PDR-016
LPDR

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

December 10, 1982

Docket No. 50-443/444

Ms. Jo Ann Shotwell
Assistant Attorney General
Commonwealth of Massachusetts
Department of Attorney General
John W. McCormack State Office Building
Boston, MA 02108

IN RESPONSE REFER
TO FOIA-82-557

Dear Ms. Shotwell:

This is in response to your letter dated November 5, 1982 in which you requested, pursuant to the Freedom of Information Act, 5 U.S.C. 552, fourteen categories of information concerning safety at the Seabrook Power Station at Seabrook, New Hampshire.

This will also acknowledge the telephone conversation you had with Mr. Roger Blond of the NRC staff, in which you further defined your request. As a result of that conversation as well as consultation with other NRC staff offices, the documents listed on the appendix were identified as being responsive to your request and are enclosed. Copies are also being placed in the NRC Public Document Room as well as the local Public Document Room at the Exeter Public Library, Exeter, New Hampshire.

This completes action on your request.

Sincerely,

J. M. Felton, Director
Division of Rules and Records
Office of Administration

Enclosures: As stated

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SHOTWEL82-557 PDR

Re: FOIA-82-557

Appendix A

1. 10/30/80 NUREG-0739 - An Approach to Quantitative Safety Goals for Nuclear Power Plants
2. 7/6/82 Memo for Chairman Palladino et. al. from William J. Dircks re: Action Plan for Implementing the Commission's Proposed Safety Goals
3. 7/8/82 Memo for Chairman Palladino et. al. from Forrest J. Remick re: Public Comments on Proposed Safety Goals
4. 7/12/82 Memo for Chairman Palladino et. al. from Forrest J. Remick re: Safety Goals for the Operation of Nuclear Power Plants
5. 7/13/82 Draft - Safety Goals for the Operation of Nuclear Power Plants
6. 2/19/82 Memo for L. G. Hulman from W. H. Regan, Seabrook Units 1 and 2 DEIS Input and Population Projections for the Year 2000
7. 2/82 Report by Michael Kaltman, Demographic and Vehicular Demands for an Evacuation Analysis of the Seabrook Station
8. 11/82 NUREG/CR-2930, PNL 4290
9. 6/27/77 Letter to D. W. Moeller from M. W. Libarkin, Appeal Board View of 100 Guideline Doses
10. 7/30/82 Letter to Ernie Murri from R. C. Tang
11. 8/27/82 Memo to William J. Dircks from R. F. Fraley, ACRS Review of the Draft Action Plan for Implementing the Commission's Proposed Safety Goals
12. 9/15/82 Memo for Forrest J. Remick from R. F. Fraley, Comments Regarding NUREG-0739, "An Approach to Quantitative Safety Goals for Nuclear Power Plants"
13. 11/82 NUREG/CR-2239, SAND 81-1549

NUREG-0739

An Approach to Quantitative Safety Goals for Nuclear Power Plants

U.S. Nuclear Regulatory
Commission

Advisory Committee on Reactor Safeguards

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NUREG-0739

An Approach to Quantitative Safety Goals for Nuclear Power Plants

Manuscript Completed: October 1980
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Advisory Committee on Reactor Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, D. C. 20555

October 31, 1980

Honorable John F. Ahearne
Chairman
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

SUBJECT: AN APPROACH TO QUANTITATIVE SAFETY GOALS FOR NUCLEAR POWER PLANTS

Dear Dr. Ahearne:

In a letter dated May 16, 1979, the ACRS recommended that consideration be given by the Nuclear Regulatory Commission to the establishment of quantitative safety goals for nuclear power reactors. The ACRS acknowledged the difficulties and uncertainties in the quantification of risk but stated its belief that quantitative safety goals and criteria can provide an important yardstick for the engineering judgment that would still be required. The ACRS further recommended that the Congress be asked to express its views on the suitability of proposed NRC quantitative safety goals and criteria in relation to other relevant aspects of our technological society.

In a letter dated June 11, 1979 to the ACRS you noted that you would appreciate any further development of the concept of quantitative safety goals that the ACRS could provide. In a memorandum dated August 14, 1979 the ACRS advised you that it was assigning the project of developing a possible approach to quantitative safety goals to its Subcommittee on Reliability and Probabilistic Assessment and that it was anticipated that about a year would be needed to develop recommendations.

The Subcommittee has now developed a preliminary proposal for a possible approach to quantitative safety goals. The proposed approach is intended to serve as one focus for discussion on the subject of quantitative safety goals and as such is expected to be only a first step in an iterative process.

The Subcommittee has prepared its discussion of the subject in the form of a report which consists of three parts, as follows:

Part 1 "On the Development of Quantitative Risk Acceptance Criteria," J. M. Griesmeyer and D. Okrent.

Part 2 "Risk Management and Decision Rules for Light Water Reactors," J. M. Griesmeyer and D. Okrent.

Part 3 "Applications and Implications of Trial Risk Acceptance Criteria," D. H. Johnson and W. E. Kastenberg.

Part 1 is primarily a review of several prior or current proposals for quantitative risk criteria which have been developed by others. Part 2 provides the preliminary proposal for a possible approach to quantitative safety goals. Part 3 provides a brief evaluation of several technologies, including nuclear power plants, in terms of criteria like those proposed in the report.

The ACRS recognizes that there are several other ongoing efforts to examine the development of such criteria. The Committee hopes that this report will contribute material useful in the process of developing an approach.

The trial approach to quantitative safety criteria, which is described in Part 2 of the report, is divided into two major tasks: the predominantly social and political task of setting the safety criteria (termed decision rules herein) and the technical task of estimating the risks and deciding whether the safety criteria have been met.

The safety criteria or decision rules are as follows:

- Limits are placed on the frequency of occurrence of certain hazardous conditions (hazard states) within the reactor.
- Limits are placed on the risk to the individual of early death, or delayed death due to cancer arising from an accident.
- Limits are placed on the overall societal risk of early or delayed death.
- An "as low as reasonably achievable" approach is applied with a cost-effectiveness criterion that includes both economic costs and a monetary value of preventing premature death.
- A small element of risk aversion is applied to infrequent accidents involving large numbers of early deaths compared to a similar number of deaths caused by many accidents each involving one or two deaths.

Each decision rule on hazard states and on individual and societal risk consists of a pair of numbers: an upper, non-acceptance limit on risk and a lower, safety goal level of risk. Compliance with the upper limit would be required for extended operation of the plant; otherwise, it must be improved within a certain period of time (to be determined) that depends upon the severity of the risk involved. On the other hand, any risk value lower than the safety goal level would be considered in compliance for the particular category of risk. However, risks must be further reduced below these safety-goal levels whenever improvements are possible that meet certain cost effectiveness criteria for risk reduction. Between the upper, non-acceptance limit and the lower safety-goal level of risk, there is a digressionary range in which case by case consideration of uncertainties, regional need for power, and alternative risks is required in the decision as to whether the plant should be allowed to operate for an extended time without modification.

The preliminary numerical values which have been suggested for use in the decision rules are primarily a matter of judgment and are intended to help stimulate discussion and evaluation in concrete terms.

Ultimately the NRC and the Congress must consider a wide range of sociopolitical and economic factors, of which direct risk to the public health and safety is but one, in arriving at a judgment on suitable risk acceptance levels.

The quantitative values suggested for use in the proposed decision rules are intended to be applicable for new light water power reactors and may be more stringent than is deemed appropriate for existing plants.

DECISION RULES

HAZARD STATES

Accidents that damage the facility represent possible forerunners of more severe accidents. A tentative set of hazard states of progressive severity has been defined and a preliminary set of limits on their rate of occurrence has been proposed, as is shown in Table 1. The limit on the frequency of a large offsite release, assuming that a fuel melt has occurred, places emphasis on mitigation as well as prevention of serious accidents. Such a division between accident prevention and accident mitigation is believed to be necessary because of the difficulty in demonstrating with a very high degree of confidence that a frequency of large scale fuel melt much less than the proposed goal of 10^{-4} per reactor-year can be achieved in view of the complexities introduced by consideration of matters such as sabotage, earthquakes, and other potential multiple failure scenarios.

INDIVIDUAL RISKS

The limits on risk to individuals living closest to the reactor site have been set well below the sum of all other risks for any age group and below those from the principal competing source of generating electricity. Lower levels were chosen (by a factor of five) for the risk of early death than for delayed death from cancer many years after an accident.

Table 2 summarizes the proposed decision rules for risks of delayed death from cancer and of early death. Note that relatively few people will have risks as high as the most exposed individuals who presumably reside close to the plant site boundaries. Most people will be exposed to risks lower than the goal levels.

SOCIETAL RISK

It has been suggested in the literature that society is risk averse when comparing a single, infrequent large accident with a number of small accidents leading to the same total number of fatalities in the same time period. A simple approach which assesses an equivalent social cost that increases faster than the actual consequences for events involving multiple deaths uses an equation of the form

$$\text{Equivalent social cost} = \sum_{\text{accidents}} (\text{Frequency})(\text{Consequence})^{\alpha}$$

in which α is greater than unity. If α is equal to one, the equivalent social cost would be the same as the expected costs (frequency times consequence). Although values of α as high as 2 or 3 have been proposed in the literature for fatalities from accidents, such values would prohibit many existing technological endeavors because of extremely high equivalent social cost, e.g., dams or large quantities of hazardous chemicals stored close to population centers. Studies performed by the Subcommittee and summarized in Part 3 of the report, indicate that society does not consciously place such high risk aversion penalties on needed activities.

In this proposal it is suggested that the social cost for delayed cancer deaths should be assessed as equal to the calculated number of fatalities (i.e., $\alpha = 1$). The range on the estimated number of people who die from the pollution arising from a coal-fired plant which generates 10^{10} kWh is about 10 to 200 (see Part 3 of the report); 10 is proposed here as the upper, non-acceptance limit on the delayed cancer deaths due to a nuclear power plant; the goal level is that there be less than two cancer fatalities per 10^{10} kWh.

To provide incentives to reduce the catastrophic potential of accidents, it is proposed to assess the equivalent social cost of early deaths with a value of α slightly larger than unity, namely $\alpha = 1.2$; hence, the equivalent early death cost of the plant, E_{ed}, would take the form

$$E_{ed} = \sum_{\text{accidents}} (\text{Frequency})\ (\text{Early Deaths})^{1.2}$$

The limits on equivalent early deaths are reduced by the same factor of five from the delayed death limits as was done for the limits on individual risk. Table 3 summarizes the decision rules for societal health risks.

SOCIETAL IMPACT REDUCTION - ALARA

It is proposed to use an "as low as reasonably achievable" (ALARA) cost-effectiveness criterion to judge whether additional risk reduction is required beyond that level of safety required to meet the other decision rules. The cost of an improvement would be balanced against the combined change in economic losses and in the risk of delayed cancer deaths, and equivalent early deaths.

While there is some limit on how much the United States can afford to spend to reduce risk from all of its technological activities, lest economic instability lead to greater risk directly or indirectly, the current perspective on nuclear reactors may be such that society is willing to spend more for LWR safety than for many other things.

It is tentatively proposed that the marginal cost limit on expenditures be set at $1 million per delayed cancer death averted and $5 million per equivalent early death averted, when "equivalent" early deaths are calculated using the coefficient $\alpha = 1.2$ for risk aversion.

It is anticipated that careful study will be required to quantify the economic losses due to property and resource damage. Because of uncertainties and the fact that some impacts cannot be quantified, it is proposed that the marginal cost limit on expenditures to reduce adverse economic impacts be twice the expected reduction in impact when applying the ALARA criterion. This also stresses prevention rather than repair of possible damage.

Table 4 summarizes the quantified ALARA criterion.

RISK QUANTIFICATION

The rest of the proposed framework deals with the technical tasks of risk quantification, which will by no means be simple. It has to be acknowledged from the beginning that there will be both large uncertainties in such risk estimates and significant differences between independent estimates of the same risk. The form of the decision rules is intended to compensate in part for some of this uncertainty. Limits are placed on the expected values of the various risks. These expected values are the weighted average of the probabilities and therefore reflect some of the uncertainties. Also, limits are placed on both the risk of a damaging accident to the fuel and on the risk of a large release of radioactive material assuming the occurrence of fuel damage, thereby requiring both prevention and mitigation.

A major tool for this effort will be a plant and site specific quantitative risk analysis which is essentially a probabilistic estimate of the distribution of risks. The details of the analysis will form a safety profile of the particular plant and site that can be used to make risk-based decisions on design and/or procedural changes. The estimated risk distribution will explicitly express the range of uncertainties and will be used in the application of the decision rules. Special attention must be given to quality assurance of the risk assessment. There must be full and explicit identification of the assumptions and limitations of the analysis, and peer review will be required. In addition, it is proposed that a procedure be established to provide a legally binding determination of those risk distribution values to be used with the decision rules. A possible approach to this aspect is the establishment of a Risk Certification Panel. After peer review of the analyses had been completed, the panel would be given the statutory authority to make a finding on the risk values to be used in the application of the decision rules.

The ACRS hopes this report proves to be useful in the ongoing effort on the development of quantitative safety goals. The Committee plans to continue to pursue the matter actively.

Sincerely,

Milton S. Plesset

Milton S. Plesset
Chairman

Table 1. Limits on Occurrence of Hazard States

Hazard State	Probability Goal	Decision Rules on Mean Frequency	
		Goal Level	Upper Limit
Significant Core Damage (> 10% of noble gas inventory leaking into primary coolant)	Less than 1/100 per reactor lifetime	$f_{cd} < 3x10^{-4}$ per reactor year	$f_{cd} < 1x10^{-3}$ per reactor year
Large Scale Fuel Melt - LSFM (> 30% of oxide fuel becoming molten)	Less than 1/300 per reactor lifetime	$f_m < 1x10^{-4}$ per reactor year	$f_m < 5x10^{-4}$ per reactor year
Large Scale Uncontrolled Release from Containment given LSFM (> 10% of Iodine inventory and 90% of noble gas)	Small, given a Large Scale Fuel Melt	$f_{R/m} < 0.01$ per LSFM	$f_{R/m} < 0.1$ per LSFM

f_{cd} is the frequency of Significant Core Damage per reactor year.

f_m is the frequency of Large Scale Fuel Melt per reactor year.

$f_{R/m}$ is the frequency of Large Scale Uncontrolled Release per Large Scale Fuel Melt.

The upper non-acceptance limits must be satisfied for extended operation of a new plant or for issuance of a construction permit. Between the upper limits and the goal levels is a discretionary range for case-by-case consideration of uncertainties and competing risk. Once the risk level decision rules have been applied, risk must still be reduced if such reduction is reasonably achievable within the cost-effectiveness criterion of Table 4.

Table 2. Limits on Risks to Most Exposed Individual

Probability Goal	Mean Frequency per Site-year		Decision Rules on Mean Frequecy per Large Scale Fuel Melt-LSFM	
	Goal Level	Upper Limit	Goal Level	Upper Limit
Probability of delayed death from cancer due to all reactors at a site over lifetime of individual <0.0005	$f_d < 5\times10^{-6}$ per site-year	$f_d < 2.5\times10^{-5}$ per site-year	$f_{d/m} < 0.01$ per LSFM	$f_{d/m} < 0.05$ per LSFM
Probability of early death due to a reactor accident over lifetime of individual < 0.0001	$f_{ed} < 1\times10^{-6}$ per site-year	$f_{ed} < 5\times10^{-6}$ per site-year	$f_{ed/m} < 0.002$ per LSFM	$f_{ed/m} < 0.01$ per LSFM

f_d is the individual risk of delayed cancer death per site year.

$f_{d/m}$ is the individual risk of delayed cancer death per large scale fuel melt.

f_{ed} is the individual risk of early death per site year.

$f_{ed/m}$ is the individual risk of early death per large scale fuel melt.

The upper non-acceptance limits must be satisfied for extended operation of a new plant or for issuance of a construction permit. Between the upper limits and the goal levels is a discretionary range for case by case consideration of uncertainties and competing risks. Once the risk level decision rules have been applied, risk must still be reduced if such reduction is reasonably achievable within the cost-effectiveness criteria of Table 4.

Table 3. Societal Health Risk Limits

Measure of Risk	Decision Rules on Societal Health Risks	
	Goal Level	Upper Non-Acceptance Limit
E_d = the expected value of: $\sum_{\substack{\text{accidents}\\ \text{and normal operation}}} (\text{Frequency})\,(\text{Delayed Cancer Deaths})$	$E_d < 2$ per 10^{10} kWh	$E_d < 10$ per 10^{10} kWh
E_{ed} = the expected value of: $\sum_{\text{accidents}} (\text{Frequency})\,(\text{Early Deaths})^{1.2}$	$E_{ed} < 0.4$ per 10^{10} kWh	$E_{ed} < 2$ per 10^{10} kWh

E_d is the average number of delayed cancer deaths per 10^{10} kWh of electricity generated.

E_{ed} is the average number of equivalent early deaths per 10^{10} kWh of electricity generated.

10^{10} kWh is the amount of electricity generated by a large (1200 MWe) power plant operating at full capacity for one year.

The upper non-acceptance limits must be met for extended operation of a new plant or for issuance of a construction permit. Between the upper limits and the goal levels is a discretionary range for case by case consideration of uncertainties and competing risk. Once the risk level decision rules have been applied, risk must still be reduced if such reduction is reasonably achievable within the cost-effectiveness criteria of Table 4.

Table 4 Quantified ALARA Cost-Effectiveness Criteria.

<table>
<tr><td colspan="2">Expenditure Limits for Impact Reduction</td></tr>
<tr><td>$1 million per delayed cancer death averted</td><td>$\$1 \times 10^6/(\Delta E_d\ L)$</td></tr>
<tr><td>$5 million per early equivalent death averted</td><td>$\$5 \times 10^6/(\Delta E_{ed}\ L)$</td></tr>
<tr><td>2 times the economic loss (due to resource damage) averted</td><td>$2/(\Delta E_r\ L)$</td></tr>
<tr><td colspan="2">A particular improvement is "cost-effective" and required if
$\text{Cost} \leq [\ 2\Delta E_r + (\$5\text{x}10^6)(\Delta E_{ed})+(\$1\text{x}10^6)(\Delta E_d)]\ L$</td></tr>
</table>

ΔE_d is the change (due to the proposed improvements) in the expected value of:

$$\sum_{\substack{\text{accidents}\\\text{and}\\\text{normal}\\\text{operation}}} (\text{Frequency})(\text{Delayed Cancer Deaths})$$

ΔE_{ed} is the change (due to the proposed improvements) in the expected value of:

$$\sum_{\text{accidents}} (\text{Frequency})\ (\text{Early Deaths})^{1.2}$$

ΔE_r is the change (due to the proposed improvements) in the expected value of:

$$\sum_{\text{accidents}} (\text{Frequency})\ (\text{Economic Losses})$$

L is the remaining lifetime of the plant in units of 10^{10} kWh to be generated and the frequencies are calculated per 10^{10} kWh. This is the amount of electricity generated by a large (1200 MWe) plant operating at full capacity for one year.

TABLE OF CONTENTS

1. ON THE DEVELOPMENT OF QUANTITATIVE RISK ACCEPTANCE CRITERIA

J. M. Griesmeyer and D. Okrent

1.1. Introduction

Society is becoming increasingly aware of the fact that risks accompany the benefit and other costs of its technological ventures, large or small. These risks cannot be totally eliminated; they can only be reduced and managed and they are only one of many sets of issues considered in the decision process. Uncertainties arise in the technical estimation of both risks and benefits, and in addition, differences among individuals in the assignment of values result in controversies over the evaluation of risks and benefits. The field of risk acceptance has been reviewed by the works of Lowrance (1976), Rowe (1977), and Van Horn and Wilson (1976), among others.

Considerable costs to society arise from the conflict over accepting technological risks: anxiety and dismay due to conflicting information; litigation costs; retrofits; and misplaced investments and costly delays that result from industry's inability to predict public risk acceptance or to plan for regulatory requirements (Starr and Whipple, 1980).

Management of risks is as much a socio-political problem as it is a technical one. It is difficult in that it is intrinsically multidisciplinary. Some of the multidisciplinary aspects are investigated in a report of work done for the National Science Foundation at UCLA (Okrent, 1977). The main question that arises is, "How safe is safe enough?" given the other costs and benefits of the technological facility. Attempts to answer this question usually employ some combination of historical precedents implied by past regulatory decisions or by statistics on a wide range of human risks (Starr, 1969; Rowe, 1977) and psychometric surveys concerning societal perceptions and evaluations of risk (Fischhoff, et al 1978, Otway, 1977). Because of the trade-offs involved in the economic, socio-political, and technical decisions to build or not to build a large technological facility, the question, "How safe is safe enough?" will not be subject to a unique answer.

The societal decision to build a particular facility ideally would be based upon the balance between all the benefits and costs of the proposed facility. Considerations would include the costs of the facility itself and the costs of choosing one of the alternatives, as well as the costs of building no facility at all. Risk costs would be included in the decision process, and general risk management criteria would be applied to all technologies. However, in the United States decisions are not usually based upon such broad considerations. Regulation of risk is most often done separately from the political and/or financial decision to go ahead with a particular project, and becomes a matter of reducing and managing the adverse impacts associated with the endeavor. There are many separate regulatory agencies, and no uniform approach to the regulation of risks exists, even within a single agency like EPA.

The realization that society as a whole has limited resources that can be expended for risk reduction has led to concern over the cost-effectiveness of safety measures. There exists a large variation in the levels of risk imposed upon society by various technologies (Okrent, 1977) and in the amount of money allocated to reduce these risks (Schwing, 1979; Cohen, 1980). Although large sums of money have been spent to make nuclear reactors safe, many people are still greatly concerned over reactor safety. Others believe that reactors are safe enough already and that a large amount of our resources is being wasted on unnecessary safety measures (Siddall, 1979). Most would agree, however, that the resources allocated for safety of reactors should be used effectively.

The large variation in the regulatory approaches of the various agencies causes some decisions to seem quite arbitrary. Also, the practice of specifying the methods for meeting the risk goals at a particular facility removes some of the incentive to develop more efficient methods of risk control. Innovative means to control risk could be encouraged by specifying the risk goals alone. However, this course may result in unduly long delays if appropriate means are not forthcoming or are themselves subject to debate. While it may not be possible to employ a completely general approach to risk management, regulatory decisions based upon a more broadly founded management philosophy and at least some quantitative decision rules may offer considerable improvement over current regulatory practice.

Specification of a justifiable and workable quantitative risk management framework is a major task if only because there is no general consensus as to the aspects of risk that must be considered or to their relative importance. Added to these problems is the difficulty of risk estimation for facilities having potential hazards which involve high consequence, low probability events, or facilities which pose relatively unfamiliar or potentially large delayed and chronic hazards. Futhermore, a particular facility or activity may appear to be the best alternative to meet an essential societal need, even though it poses a large identified hazard which must be managed.

In this paper, some of the major considerations for effective management of risk are discussed, with particular emphasis on risks due to nuclear power plant operations. Although there are impacts associated with the rest of the fuel cycle, they are not addressed here. Next, several previously published proposals for quantitative risk criteria are reviewed. They range from a simple acceptance criterion on individual risk of death to a quantitative risk management framework. The final section discusses some of the problems in the establishment of a framework for the quantitative management of risk.

We do not consider occupational risks within the context of this paper.

1.2. Risk Management Considerations

1.2.1. Decision Levels and Impacts

Several levels are involved in the decision to build a particular power plant. These focus on the need for power, the technological options, alternative sites and risk acceptance. The interactions between economic, socio-political, environmental and public health and safety impacts should be considered and factored into the decision at each level. For example, health is to some extent positively correlated with standard of living, which may be lowered if energy is not available or if energy costs become much higher as a result of expenditures for safety improvements. Also, the costs of required safety measures for one technology may force the choice of an alternative technology having larger impacts, if the overall economics of the first technology become unfavorable.

Acceptable risk is most properly addressed in the context of alternatives, including the option of not building a facility to supply a particular societal need or want. Large uncertainties in the level of risk must also be considered. The uncertainties arise from shortcomings both of data and of models to predict risk. Sometimes conservative estimates are used to put upper bounds upon risk. However, without estimates of the uncertainties or methods to determine the relative amount of conservatism among alternatives, conservative estimates may distort the relative impacts of the various options and may lead to a less than optimal choice between them. The problem is further complicated because the different types of impact are not readily comparable.

In order to gain perspective it might be useful to construct a hierarchy of impacts according to magnitude and to extent, i.e., local, regional, or global effects. Moderate negative effects which are local in nature may be preferable to moderate negative effects which are regional in extent, etc. The regional need for power, based upon economic and socio-political considerations, may be such that a power plant should be built; the accepted environmental and public health and safety impacts (local and regional) will be determined by the choice of site and technological alternative and by the resources allocated to reduce those impacts. The impacts of procuring and processing the fuel will also depend upon such choices.

1.2.2 Approaches to Risk Management

Technological hazards arise as a consequence of endeavors to satisfy societal needs and wants. In part, such hazards can be modified by changing societal wants, by choosing a different technology to satisfy the wants, or by improving the technology to prevent the occurrence of the hazard or to mitigate the consequences (Fischhoff et al,1978). The Nuclear Regulatory Commission (NRC) has the authority to require and approve improvements in the nuclear power plant, once the choice to build a reactor has been made. It must decide if the plant is safe enough, or in other words if enough resources have been spent to ensure safety. While the NRC, in environmental impact statements, assesses and compares the use of alternative technologies with nuclear, the NRC may not have the authority to choose between power generating technologies. However, it may force an alternative choice by its stringent safety requirements.

Various approaches have been used to determine whether a technological facility is safe enough; these include professional judgment, cost benefit and cost effectiveness considerations, comparison with background hazards, public preferences, or comprehensive analysis of various options. Each approach has its advantages and disadvantages. A catalogue of caveats for these approaches has been compiled by Fischhoff et al. (1980).

Professional judgment relies on good professional practice to ensure that failures are not likely. However, failures in equipment do occur, and some means must be developed to decide what failure rates are acceptable. The costs of the failure rates can be estimated, and the expected consequence per year can be added to the overall costs of the facility in a cost-benefit analysis. However, serious problems arise in assessment of both costs and benefits (Baram, 1980). The measures of effect are not easily converted to a single unit such as money, and some cannot be estimated without tenuous assumptions which often are not adequately stated in the report of the results. This lends itself to intended and unintended bias in the presentation of the analysis and distortions in its interpretation.

In any case, the risk benefit type of analysis for a particular technology for the generation of electricity should be done for the whole fuel cycle. Similarly, comparative risk studies may be used to help choose between two alternative technologies; however, such comparative analyses become less applicable for determining the level of acceptable risk for separate parts of the fuel cycle such as mining and milling operations, or just the power plant itself.

In order to efficiently allocate societal resources for risk reduction, limits may have to be set not only on the expected risk of a facility but also (or rather) on the amount of money spent per unit of risk reduction. Beyond a certain expenditure the money may be better spent to reduce the risk associated with other societal activities. It has been suggested that there is a lower bound below which total risk cannot be reduced for each facility. The cost per unit of total risk reduction will become infinite when the risk involved in producing the safety equipment becomes equal to the anticipated reduction in risk (Black et al, 1979) or when risk increases more in other segments of society because resources have been diverted (Siddall, 1979).

Care must be used in the application of cost effectiveness criteria. For example, it was found that to reduce local health effects from facilities which burn fossil fuel, it was less cost effective to remove more sulfur and particulates from the flue gas than it was to increase the stack height and disperse the pollutants. However, it was found that the longer residence time in the air allows more of the sulfur dioxide to be converted into sulfate and results in acid rain great distances from the stack. The pollution problem has not been solved; a local health problem has only been converted into a regional environmental problem and may still result in significant health effects because, while the risk to each individual has been reduced, more people may be exposed.

As an alternative to or in conjunction with economic considerations, acceptable risk could be determined by some assessment of societal preferences. Some indirect assessments employ retrospective examination of choices implied by statistics on a wide range of human risks or by past regulatory decisions (Starr, 1969; Rowe, 1977). At least two major assumptions are made if one applies this approach without modification: that what existed in the past was accepted then and is indicative of what will be accepted in the future; and that society was well informed concerning the nature of risks associated with its actions. Neither of these assumptions is generally valid (Slovic et al, 1980; Fischhoff et al, 1978). Using precedents implied by past regulatory decisions is also difficult because the different types of risk are not easily compared and the statutory mandates of the regulating agencies vary significantly. And, societal preferences are not easily deduced from hazard statistics since the level of risk will depend not only upon the hazard potential of a particular activity but also upon the public awareness of the hazard, the ease and cost of its control, and the relative political power of those who benefit from the activity and those who are burdened by the risk.

Direct methods to assess public preferences include opinion polls and psychometric surveys concerning societal perception and evaluation of risk (Otway, 1977; 1978; Slovic et al, 1980; Fischhoff et al, 1978).

Studies have shown that perceptions of risk by groups of lay people sometimes have systematic variations compared with each other and with the statistically measured risks (Slovic et al, 1980; Fischhoff et al, 1978); that perceived benefits are negatively correlated with perceived risks (Otway, 1977; Fischhoff et al, 1978); that expert risk assessments are also susceptible to bias, particularly underestimation; and that new evidence is often interpreted to reinforce existing beliefs (Slovic et al, 1980). These findings indicate that it would be no simple matter to incorporate aggregated public attitudes and perceptions in a meaningful and useful way into risk acceptance criteria. Even the solicitation of these attitudes requires care because the form and sequence of the survey questions may strongly influence the response (Plott, 1978; Hershey and Schoemaker, 1980).

Basing risk acceptance solely on perceived risk and without consideration of the alternatives has a number of disadvantages. It virtually assures that limited resources for risk abatement will be misallocated, and leaves open the possibilities that societal needs will not be met or that some risks will be much higher than necessary. Furthermore, societal perceptions have been subject to reversals in thinking in the past (e.g., the U.S. attitude to civil rights in the 1930's; the German attitude to Hitler in the 1930's; and the U.S. attitude toward oil shortages and an energy crisis in the mid-1970's).

1.2.3 Special Considerations for LWRs

Risks have been frequently categorized according to several dichotomous factors such as whether the exposure to the risk is voluntary, new, common, catastrophic, dreaded, lethal or man-originated, etc. (Starr, 1969; Lowrance, 1976; Rowe, 1977; Otway, 1977; Fischhoff et al, 1979; Litai, 1980). Nuclear power is unique in that it is in a category by itself on these perceptual scales. It is perceived as new, uncommon, dreaded, most likely lethal, involuntary and potentially catastrophic. These factors have been used to explain the public's special concern over nuclear power. They also hinder the determination of acceptable risk by simple comparison with other technologies.

Current opposition to nuclear energy might be reduced by requiring lower risk acceptance limits for reactors than for other technologies. However, according to Otway (1978), the reasons for opposition to nuclear power are related to social and psychological factors which probably would not be affected by changes in reactor technology that reduce risk. Bodansky and Schmidt (1979) develop this point by discussing the opposition to nuclear power in three parts: (1) concerns about nuclear radiation; (2) concerns about nuclear weapons proliferation; and (3) concerns about the general nature of society and its future development. They suggest that the last set of concerns relating to big government, centralized and impersonal technology, and a technological elite, gives rise to the largest opposition to nuclear power, which is a symbol for these concerns.

Stricter safety criteria may not calm these concerns. In fact, overly strict criteria may give the impression that the strictness is needed to compensate for some unknown factor that may have been overlooked (Otway, 1978). If it cannot be demonstrated that the strict criteria have been met, the acceptance problem may be aggravated if at some later date the criteria are relaxed. Nevertheless, it can be argued that society wishes nuclear plants to be safer than alternative energy sources. It can also be argued that much of the concern about LWR safety arises from a considerable uncertainty as to whether the stringent criteria intended to limit the frequency of a serious accident have actually been met.

Proliferation of nuclear weapons is a concern not so much for the nuclear power plant itself as for the entire fuel cycle. As such, the concerns over proliferation as well as those over the nature of society may strongly influence the choice of technology to generate the desired electricity but are not such important factors in determining the acceptable risk due to the power plant itself.

The possibly catastrophic nature of the effects of a large radiation release coupled with a low frequency of occurrence make the acceptable risk question much more complicated than just setting limits on the expected average consequences per year. While large, fairly constant yearly losses may usually be planned for and accommodated by societal adjustments, a large catastrophe requires consideration of the resilience of society, that is, its ability to recover.

Siting policy can be especially effective in helping to reduce the probability and the magnitude of early fatalities from an accident. The number of latent health effects from a serious accident, however, depends upon the integrated man-rem dose, which would be hard to reduce markedly by siting practice alone in the eastern United States, although it can be clearly affected (e.g., consider the Zion versus the Browns Ferry sites). The incremental risk of cancer above background from an exposure of 1 rem to an individual is not large statistically, but there may be substantial trauma that is real and far exceeds the statistical risk in its impact and importance. In fact, it may be that safety criteria should deal with accidents of the nature and magnitude of that at Three Mile Island, which did not have large, offsite, radiological consequences.

More study appears to be needed concerning the potential costs and effects of contaminating important resources such as a large aquifier, a large area of fertile farm land, or large residential areas.

As mentioned above, the questions of acceptable risk must be raised in the context of several interacting decision level and impact considerations. The nuclear power option is not alone in its potential for very large adverse consequences. Large scale use of fossil fuels appears to lead to an increasing CO_2 content in the atmosphere, which may cause devastating climatic changes if it continues. Of course, the more immediate effects of the fossil fuel combustion are potentially major air pollution effects on health and the increase in the acidity of rain downwind. The latter effect has become a major environmental problem by degrading whole eco-systems. Unfortunately, the economic and health impacts of this damage are not easily assessed, though the impacts may be significant. On the other hand, should excessive dependence of the United States (and other industrial powers) upon foreign oil supplies significantly increase the chances of war, this may dwarf all other risks.

Societal willingness to accept the risks of potentially large impacts of the nuclear option must depend upon the potentially large impacts of the alternatives. The only certainty in the consideration of criteria for acceptable risk is that there will be conflicts whenever societal decisions impose risks on a particular group. Analysis will help clarify the issues, but it will not remove all of the uncertainties or bring about consensus. Quantitative decision rules in a clear framework may provide a practical compromise between analytical and judgmental approaches to acceptable risk (Starr and Whipple, 1980). In order to fulfill this function, the logic behind the rules and framework must be easily understood both by technical people and by the general public and there must be some logical straightforward way to demonstrate that the criteria have been met (Rasmussen, 1978/79). Development of the framework and the numerical values used in the rules will require much work and input from many parts of society.

1.3 Some Previously Presented Proposals

The overall philosophy and intent of the particular policies toward risk determine the form and scope of the various risk acceptance criteria reviewed below as well as the proposed numerical parameters. The criteria may deal with effects such as deaths or property damage, with exposures to harmful agents such as radiation or pollutants, or with the frequency of certain types of accidents. Criteria that address effects might be more easily related to a generalized policy toward technological risks, yet be more difficult to apply than criteria that deal with technology-specific issues.

The risk criteria described below can be roughly categorized into three groups: those that set limits on individual risk of death only; those that consider frequency of accidents and magnitude of the consequences; and those that imbed the criteria in risk management frameworks that, at least in part, consider risks from alternatives or other societal endeavors. Some, but not all, of the criteria apply specifically to nuclear reactors.

1.3.1 Individual Risk Criteria

One of the early proposals for quantitative risk criteria for nuclear reactors was made by Adams and Stone (1967) of the Central Electricity Generating Board of Great Britain at an IAEA Symposium on Siting and Containment. They proposed that the parameter determining acceptable siting be taken as individual risk. Although the numerical limit would be a matter for governmental decision, they suggested that an incremental increase in an individual's chance of death per year that is smaller than the demographic variation in the United Kingdom of that chance of death per year would be inappreciable and acceptable on those grounds. Differences significantly greater than 10^{-5} per year occur between England, Wales, Scotland and Ireland, and they proposed that an incremental individual risk of 10^{-5} chance of death per year would be acceptable. For immediate deaths and a plant lifetime of 30 years this would correspond to a statistical loss of life expectancy of about 6 days, while for death delayed until 10 years after exposure the statistical loss is about 3 days. Of course, the loss is much larger for the actual victims and zero for all the others.

Adams and Stone arrived at a siting policy based on the above criterion which requires the following: an exclusion area; a controlled area, where development that would prevent emergency action would not be allowed; and then an area of unrestricted population. They did not, however, discuss how one should demonstrate that the criterion had been satisfied. In fact, they argued that community or aggregate risk criteria based on the total potential number of casualties would not be useful because the uncertainty in that number, due to the magnitude and conditions of release in an accident, is far greater than the differences that choice of site could make. The policy did not consider property or other resource damage.

- The apparently positive correlation between standard of living and health has been used by Bowen (1975) to develop a general risk acceptance criterion for technological activities in the United Kingdom. He suggests that the risks imposed upon society should be negligible or balanced by benefits. However, risk levels that can be scientifically supported, say a 10^{-5} chance of death per year, cannot be considered negligible in all situations, and balancing by direct individual benefits is not possible in cases where the victim cannot be readily identified in advance, for example, the one excess cancer fatality that might be expected from the TMI accident. Bowen argues that the balance should be done macroscopically.

He assumes that the observed annual increase in life expectancy in the U.K. is due to overall societal efforts, i.e., its investment in "the industrial machine" of which any technological facility forms a part. An additional yearly risk of death of 10^{-5} from a new facility roughly balances the expected increase of an individual's life expectancy during one year. Bowen asserts that if no investment is made in the industrial machine, the annual increase in life expectancy may stop altogether. Hence, he chooses 10^{-5} per year as a reasonable limit on the individual risk of death from a single facility and assumes that no individual is exposed to more than a very few technological facilities.* If the increase in life expectancy per year is larger than that in the U.K. (i.e., 0.05 years/year), a country might accept technological activities involving a correspondingly larger risk, at least for accidents which are not truly catastrophic.

With regard to accidents having a potential for a major disaster, Bowen argued against requiring a lower frequency limit for which compliance would be difficult to demonstrate or even achieve. He suggested instead that the 10^{-5} limit should be demonstrated to a high confidence level when there is potential for a large catastrophy. He felt that if a large accident were to occur, it would not be easy to distinguish between just being "unlucky" or having accepted a risk analysis that greatly underestimated the risk. Being "unlucky" could be prevented by achieving a lower probability for large accidents but at the expense of investments into the industrial machine. Bowen argued that, if the aim is to have a small chance (i.e. 1%) of having a large catastrophe in one's lifetime, a limit of 10^{-5} events/year demonstrated to high confidence, say 99% or so, would be adequate; it would not help to

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*In a personal communication, he has since indicated that a larger level of risk, more like 10^{-4} per plant per year, may be more practical for the individual living near a large chemical facility (Okrent, 1977).

restate the aim as 10^{-7} events/year, and besides, it may divert resources, attention and effort.

Bowen did not distinguish between deaths occurring immediately after an accident and those that are delayed for a few years, nor did he consider risks other than individual fatalities.

1.3.2 Frequency-Consequence Approaches

The previous criteria dealt specifically with individual fatality risks without directly including limits on other types of risk or addressing the effects of a large scale accident. In the four following proposals, special attention is given to the magnitude of an accident. A basic common assumption is that the limiting frequency of a particular accident should depend in some way upon its magnitude. Three of the sets of risk criteria deal with nuclear power plant risks. The first proposal suggests a limit on the frequency of accidental release of radioactive material, the second, on frequency of individual exposure, and the third is concerned with limits on the fatalities due to accidental exposure. The final proposal in this section relates the required structural integrity of a building to the intended use of the building and the number of expected injuries, should it fail.

- At an IAEA Symposium on Siting and Containment, F.R. Farmer (1967) of Great Britain, presented a much-to-be quoted paper, "Siting Criteria - A New Approach." In it he proposed that probabilistic analysis be employed in reactor safety assessment and suggested that the safety criterion of less than 0.01 premature deaths per reactor year be adopted. In addition, he proposed that a risk acceptance limit line be used to judge the acceptability of the estimated occurrence frequency for any particular accident. The severity of the accident was measured by the release in curies of iodine-131, one of the volatile fission products of greatest importance in thermal reactor accidents.

The Farmer limit line is reproduced in Figure 1.1. The acceptable frequency of occurrence of an accident fell off as the consequences increased with a rate such that the expected contribution to risk (frequency times consequences) was less for very large accidents than for smaller ones (a negative slope of -1.5 on a log-log plot). Farmer suggested that only a relatively few events would be near the line for any reactor, and that these would lead to the principal contribution to premature deaths. Later British papers (Beattie et. al., 1969; Farmer and Beattie, 1976) developed a mathematical interpretation of the line and gave it a slope of unity. Risk assessments were made by assuming that accidents could be grouped to occupy each decade, both in frequency and magnitude of release, out to some limiting release.

The Farmer limit line does not deal specifically with effects dependent upon population density and other conditions around

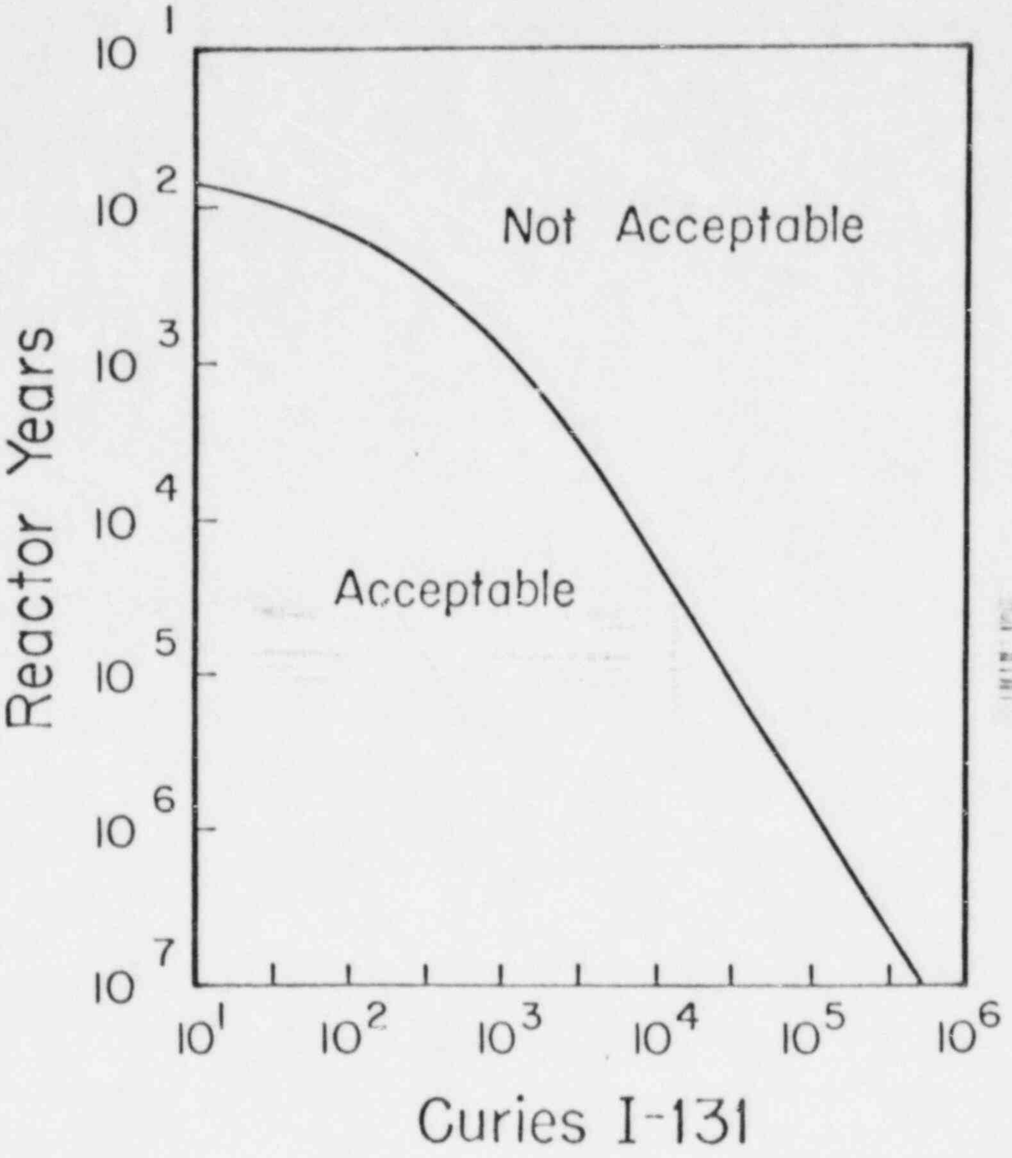

Fig 1.1 Farmer release frequency limit line (Farmer, 1967)

the site. Therefore, the actual limits on effects, such as risk to individual, property damage, or number of expected fatalities, must be estimated from site specific analyses.

In late 1978, a proposal for probabilistic safety requirements for use in licensing CANDU nuclear power plants was submitted by the Inter-Organizational Working Group to the Atomic Energy Control Board of Canada for general public comment (AECB, 1978). The requirements are in the form of quantitative frequency dose limits and were intended to be conservative in ensuring that the likelihood of a lethal dose (200-400 whole body rem) to any nearby resident would be less than 10^{-6} per reactor year. Table 1.1 and 1.2 give the proposed reference values for radiation exposure.

The process failures include any problems with the reactor core, heat removal systems, control rods, or instrumentation needed for regulation and control in normal operations. Special Safety Systems include "protective devices," such as the automatic shutdown system and emergency core cooling system, and "containment provisions."

Serious process failures would be required to occur less than 10^{-3} per year, and the unavailability of the Special Safety Systems should be less than 10^{-3}. Estimates of the process failure rate might turn out to be less than the limit, but the credit to be used in calculating release frequency was to be no less than 10^{-3} per

TABLE 1.1 - PROPOSED REFERENCE VALUES (AECB, 1978)

Serious Process Failures

Reference Dose Interval (In absense of Special Safety Systems) Rem		Reference Value for the Sum of the Predicted Rates of Occurrence of Failures within the corresponding Reference Dose interval
Whole Body	Thyroid	(Per Reactor Unit Per Annum)
0-0.05	0-0.5	10^{-1}
0.05-0.5	0.5-5	10^{-2}
0.5-5	5-50	10^{-3}

TABLE 1.2 - PROPOSED REFERENCE VALUES

Process and Special Safety System Failures

Reference Dose Interval Rem		Reference Value for the Sum of the Predicted Rates of Occurrence of Failures within the corresponding Reference Dose Interval
Whole Body	Thyroid	(Per Reactor Unit Per Annum)
5-10	50-100	10^{-4}
10-30	100-300	10^{-5}
30-100	300-1000	10^{-6}

Note: The actual dose to the individual in table 1.1 will be less than reference value which does not give credit for the Special Safety Systems.

year. Similarly, the lowest unavailability of the Special Safety Systems that could be used in the exposure frequency calculation was 10^{-3}. These restrictions were intended to compensate for the uncertainties involved in the risk assessments and to force consideration of both prevention and mitigation of accidents.

In applying the proposed criteria, the applicant for a nuclear power plant construction permit would be instructed to: (1) list all events for which rates of occurrence and consequences are to be predicted; (2) analyze each event and predict its rate of occurrence and its consequences; and (3) sum the rates of occurrence of all events whose consequences fall within each of the reference dose intervals. No sum would be allowed to exceed its corresponding reference value.

There was difficulty in fitting events such as earthquakes and sabotage into the framework and rationale used for dealing with equipment failures caused by component weakness or system maloperation. The report did not make clear how completeness of the risk analysis was to be ensured nor did it elaborate on how to treat human error or other internal situations that might compromise the independence of the process equipment and Special Safety Systems, and cause them to fail simultaneously.

The magnitude of a particular accident is measured in this proposal by expected dose to an individual. The concern is to ensure that lethal doses to the individual arise at a rate less than 10^{-6} per reactor year. As such, the criteria do not address the total number of immediate fatalities that might be caused by the accident. The report does not discuss latent effects such as cancer, but individual latent risk limits are implied by the frequency dose criteria.

- G.H. Kinchin of the Safety and Reliability Directorate of the UKAEA has proposed a quantitative set of public health and safety criteria for nuclear reactors (1978; 1979). Because of the difficulty in balancing economic advantages against health risks, he suggested that the criteria should be conservative. Unlike the previous two sets of criteria, Kinchin proposes limits on the expected effects rather than on the magnitude of release or expected dose. The criteria put limits on individual and aggregate societal risks of both immediate and delayed death due to reactor accidents.

The conservative objective was to make the risk of immediate death to an individual member of the public small compared with other involuntary risks, and a value of 10^{-6} per reactor year was suggested. Kinchin stated that possibly a higher value would be acceptable.

Kinchin suggested that in the attempt

> "to arrive at a criterion for the risk of delayed deaths, the following thoughts might be kept in mind:
>
> (a) death at some relatively distant date in the future is preferable to immediate death;
>
> (b) the effect of radiation-induced cancers on the life expectancy of a young person is greater than on that of an older person;

(c) an annual death rate of 10^{-6}/year, as proposed above, would be caused by an accident giving a total probability of delayed deaths of 3×10^{-5};

(d) it seems that radiation exposure just insufficient to cause immediate death may not give rise to fatal malignancy;

(e) for the specific malignancies induced by irradiation, comparison should be made with some of the figures for cancer... rather than with the lower probabilities of early death due to, say, electrocution or drowning." (Kinchin, 1978)

Taking these points into account, he proposed that the limit on the annual accidental probability of inducing delayed death to the individual should be 3×10^{-5}/year. Although noting that this was a factor of 3 higher than the upper end of the range suggested by ICRP, he felt it difficult to justify a relative acceptable limit factor of less than 30 between death in 10 years time and death today (Kinchin, 1979).

Limits on aggregate societal risk of immediate and delayed deaths are specified by a pair of frequency versus consequence curves.

The rationale for the early death limit curve was: "It would not seem unreasonable to propose a criterion that the total risk from nuclear reactors should be roughly comparable with that from meteorites." Each of an assumed population of 100 reactors in the U.K. was assigned 1/100 of the total risk. The societal delayed death curve was formed using the same factor of 30 used to set the limit on individual delayed death risk. The limit curves are shown in Figure 1.2 redrawn from Kinchin's 1979 proposal.

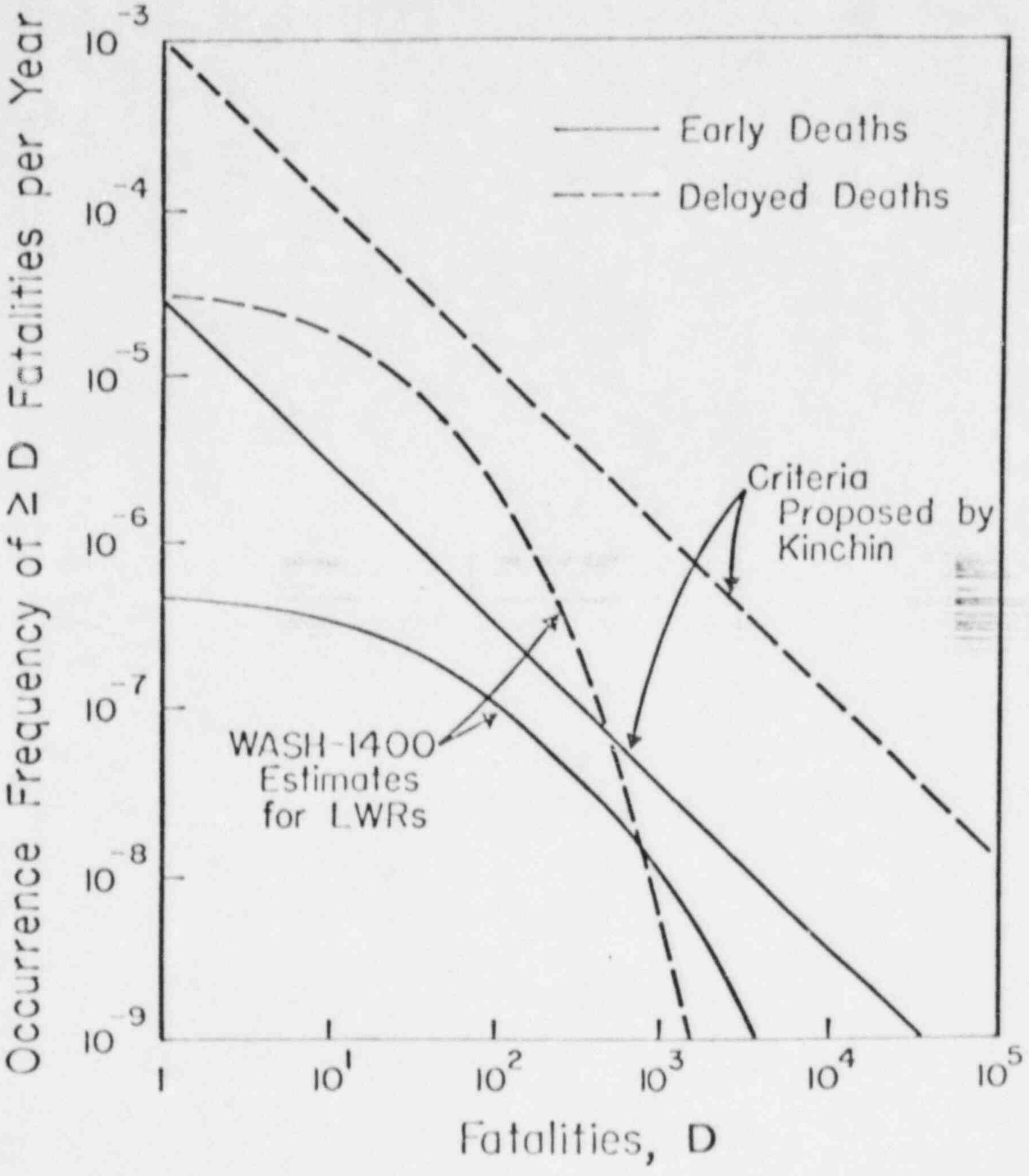

Fig 1.2 Criteria proposed by Kinchin (1979)

Specification of limits on effects allows comparisons with other risks and flexibility in design and siting to achieve the safety goals. Kinchin emphasized that the design goals have to be supplemented by good engineering practice and quality assurance programs to ensure that the safety goals are met. For any particular case, individual risk of early and delayed death at the site boundary and the corresponding societal risks of early and delayed deaths would be examined. The most limiting criteria would then be applied.

- The Construction Industry Research and Information Association (CIRIA) of the U.K. has attempted to rationalize the safety and serviceability factors for structures such as buildings and bridges by relating them to social and economic criteria (CIRIA, 1977).

These criteria were expected to vary with the size and intended use of the structure and with the prevailing social and economic climate in the country in which it would be built. They found it convenient to consider human life and economic consequences of failure separately, but acceptable risk levels in heavily populated buildings may be found by a combined socio-economic criterion.

Historically, the annual risk of death to any person in the U.K due to collapse of a structure is on the order of 1.4×10^{-7} per year. This was taken to indicate that the public expects these risks to be small compared to other risks to which they are exposed. The degree of safety required also was intended to reflect the public aversion to the failure of each class of structure.

By reference to statistics on each class of structure, the yearly acceptable risk of failure, R_f, was deduced to have the form

$$R_f = \frac{10^{-4} K_s}{N_r}$$

where N_r is the average number of people expected to be within or near the structure if it were to collapse and K_s is the social criterion factor, given in Table 1.3 for various types of structures. The failure risk limit in each class is inversely proportional to the number of people affected by the failure. However, the social criterion factor is also seen to be smaller for structures that generally involve more people or serve important public functions, so that there would be a very strong aversion to failures that could injure a large number of people if the criterion were to be used.

Table 1.3 Social Criterion factors, K_s (CIRIA, 1977)

Nature of Structure	
Places of assembly, dams	0.005
Domestic, office or trade and industry	0.05
Bridges	0.5
Towers, masts, offshore structures	5.0

The economic criterion was formed by minimizing a total cost function E_t, given by

$$E_t = E_i + E_f R_f n_d$$

where E_i is the initial cost, E_f is the consequential cost of failure, and n_d is the design life in years.

CIRIA noted that, historically, society has responded in a very risk averse manner to large consequence failures and this has lead to disproportionate expenditures to reduce those risks. Although this aversion cannot be totally eliminated, they suggested that it could be rationalized somewhat by setting a limit on the expenditure, M, to prevent a failure:

$$M < \frac{\nu N_r}{K_s}$$

where ν is a constant and N_r and K_r are defined as above. If ν is set at £ 25000, this would imply an expenditure of about $\$10^6$ per life saved for low risk structures for which $K_s = 0.05$.

1.3.3 Risk Management Approaches

Two common premises of the following risk management approaches are: that society has a limited amount of resources to allocate for the reduction of the risks that accompany the benefits of its endeavors and that these resources should be allocated wisely. They reflect concern that improper actions to reduce risks may not minimize risk and may even give rise to an increase in overall risks. The first two approaches are concerned with general societal risk while the last two deal specifically with nuclear power plant risks.

•As a starting point for discussion on the subject of risk acceptance criteria, Okrent and Whipple (1977) described a simple quantitative approach to risk management which incorporated the following principal features:

Risk assessment

Each risk-producing facility, technology, etc., would have to undergo assessment both of risk to the individual and to society. The risk assessment would be performed under the auspices of the manufacturer, owners, etc. It would be independently reviewed and evaluated. The decision on acceptability would be made by a regulatory group. For practical reasons, there would be some risk threshold below which no review was required.

Graduated limits on individual risk

Societal activities would be divided into major facilities or technologies, all or part of which are categorized as essential, beneficial, or peripheral to society. There would be a decreasing level of acceptable risk to the most exposed individual (for example, 2×10^{-4} additional risk of death per year for the essential category, 2×10^{-5} for the beneficial category, and 2×10^{-6} for the peripheral category).

Allowance for uncertainties

The risk would be assessed at high level of confidence (say 90 percent) which thereby reflected the uncertainties and provided an incentive to obtaining better data, since the expected value of risk must be smaller, the larger the uncertainty.

Internalization of residual risk costs

To provide incentive to reduce risk and balance some inequities between those who receive the benefits and those who are burdened by risk, the cost of the residual risk would have to be internalized, generally via a tax paid to the federal government, except for risks which are fully insurable and, like drowning, are readily attributable. The government would, in turn, redistribute the risk tax as national health insurance and/or reduced taxes to the individual.

Modest risk aversion

Risk aversion to large events would be built into the internalization of the cost of risk, but with a relatively modest penalty. If some technology or installation posed a very large hazard at some very low probability, and many do, a case by case decision would be required, with considerable emphasis on the essentiality of the venture.

Cost effective reduction of residual risk

A limit on the marginal cost of risk reduction could be imposed. A safety improvement would be required if the marginal cost was

> lower than the limit, but not required if above. This would be a quantification of the ALARA (as low as reasonably achievable) criterion, although an incentive to reduce risk as well as the uncertainty in knowledge of risk would already have been provided by establishing a suitable level for the risk tax.

The authors realized that their approach may be both too complex and too simple but hoped it would stimulate discussion of the question, "How safe is safe enough?"

Also to promote discussion on risk management, the late C.L. Comar wrote an editorial for Science (1979) entitled: "Risk: A Pragmatic De Minimis Approach" which is reproduced below:

> Society is becoming well informed and anxiety-prone about technology-associated risks, which leads to desire their elimination. The logical and traditional approach is first to estimate the risk, a scientific task. Then comes the issue of risk acceptance, a most difficult step--moving from the world of facts to the world of values. Ideally, judgments involving risk acceptance should be made on society's behalf by a constitutionally appropriate body. But no such public decisionmaking process exists. We make do with disparate efforts of individuals, special-interest groups, self-appointed public interest groups, and legislative, judicial, and regulatory systems. However, if at least very large and very small risks were dealt with on the factual basis of effects, the individual and social value systems could be accommodated to some degree and much confusion avoided.
>
> It is human nature to be concerned primarily with effects on our own person and family and secondarily with effects on the population at large. Unfortunately, although we can predict statistical effects on populations, there is no way to predict effects on individuals. This is why fortune tellers never become as rich as

insurance companies. We need them to define actuarially the existing state of well being and calculate effects on it.

Each person has a probability of dying in any particular year, the value depending mainly on age. The existing probabilities are well known for the United States. For example, in 1975, 1.89 million died out of a population of 213 million, giving an overall probability of 1 in 113. For some specific age groups the values were: 1 to 4 years, 1 in 1425; 5 to 14 years, 1 in 2349; 25 to 34 years, 1 to 692, 55 to 64 years, 1 in 67. We can now answer the question, "What does changing a risk do to a person's existing probability of dying?" For instance, if a young child were exposed to an additional risk of 1 in 100,000 (0.014 in 1425) in 1975, his overall risk for that year would be 1 in 1425 plus 0.014 in 1425, or 1.014 in 1425. For the purpose of discussion some guidelines, which may depend somewhat on age, can now be stated in terms of numerical risk:

(1) Eliminate any risk that carries no benefit or is easily avoided.

(2) Eliminate any large risk (about 1 in 10,000 per year or greater) that does not carry clearly overriding benefits.

(3) Ignore for the time being any small risk (about 1 in 100,000 per year or less) that does not fall into category 1.

(4) Actively study risks falling between these limits, with the view that the risk of taking any proposed action should be weighed against the risk of not taking action.

Clearly, these suggested guidelines are a gross oversimplification. The unfortunate, overtaken by a one-in-a-million catastrophe, have a 100 percent chance of harm. The hard fact is that attempts to eliminate risks for the unfortunate few tend to markedly increase them for the rest of a large population. This idea is most difficult to defend practically, especially when the unfortunate few are known and the unfortunate many are nameless. In addition, it is necessary to take into account such matters as validity and uncertainty in risk

> estimates, nonlethal and esthetic effects, voluntary versus involuntary risks, societal abhorrences, and the strange versus the familiar.
>
> Nevertheless, other than depriving the news media of a ready source of attention-grabbing items, the pragmatic de minimis approach should serve to promote understanding about how to deal with risk in the real world; encourage identifiers of risk to provide risk estimates; focus attention on actions that can effectively improve health and welfare and at the same time avoid squandering resources in attempts to reduce small risks while leaving larger ones unattended; and prevent anxiety, apathy, or derision as a response to the increasing recognition that we apparently live in a sea of carcinogens (the "today risk").
>
> (Copyright 1979 by the American Association for the Advancement of Science.)

Various groups within the nuclear industry have been advocating quantitative safety goals for some time, and the following two approaches to the formulation of such goals illustrate some of the current thinking.

- The director of the Nuclear Safety Analysis Center (NSAC), E.L. Zebroski, has presented their thoughts at the 7th Energy Technology Conference in Washington in March of 1980 (NSAC, 1980) and later in July at a subcommittee meeting of the Advisory Committee on Reactor Safeguards (NSAC, 1980a).

A safety goal is needed to regulate hazards, according to NSAC, because without a practical safety goal, there is a tendency to strive in vain for near-zero risk from any defined hazard. Extreme reductions in a particular risk may lead to increases in other, less well-studied risks. No guide is found in present legislation for regulation to avoid alternative risks due to short sighted policy. These risks include deprivation, social chaos and possible constribution to chance of war due to overregulation of domestic energy supplies. As one measure of social cost, they estimate that nearly one trillion dollars will be added to fuel bills in this century due to delays, cancellations or non-commitments of nuclear units.

NSAC suggested that any set of safety goals for nuclear power plants should have the following attributes: (1) They must provide an objective basis for regulator and utility analysis and agreement on what is "safe enough". This must be clearly a "non-zero" risk goal that considers the relative risks of the main alternative sources of electricity and the social cost of shortages, interruptions and large increases in costs. (2) They must be describable in terms which are understandable and acceptable to reasonably informed laymen. They need not be acceptable to everyone, especially those with extreme uncompromising views. And finally, (3) They must include definitions for practical methods for design and operating decisions that make full use of best-available data and decision processes.

As a possible first cut at the formulation of a safety goal, Zebroski suggested the following features:

(a) Reactor design and operation should insure that the expected time to another core-damaging accident is not less than 30 years for the whole population of reactors in the U.S.

(b) Reactor and containment system design and operation should insure that, given the occurrence of a core damaging accident, there would be only a 1/1000 chance that radiation would be released causing a total dose of greater than one rem to any member of the public.

(c) The nuclear risk should be maintained at no more than one-third of the total risk of the two largest alternative sources of electricity.

(d) Improvements to reduce nuclear risk to 1/10 or less of the main practical alternative sources should be sought, but implemented only if they are cost effective and have no measurable effect on the cost or availability of energy.

(e) Emergency plans should provide a less than 1 in a hundred chance that the total population dose be more than 5000 man-rem even if containment failure were to occur.

To implement (a) and (b) relative risk assessment methods were to be used with existing operating experience as a base. A factor of five improvement was considered adequate to meet the goals. Statistically rigorous formulations with defined confidence levels and permissible error bounds were to be used and the cumulative effects of the actual total population of operating reactors were to be included.

It was also suggested that the goals should be stabilized for at least 10 years to prevent the delays associated with regulatory uncertainties.

The proposal clearly indicates that NSAC believes that the reactors are very much safer than the alternatives and that the goals suggested are conservative relative to the safety levels achievable by the alternatives. However, there is some question as to how one would compare the risks of different types which arise from the various alternatives (e.g. expected number of fatalities may not be an adequate measure when comparing low frequency, high consequence accidents with the chronic risks of the coal fuel cycle). The limit of 5000 total man-rem, given an accident which breaches the containment, drew comment at the ACRS subcommittee meeting. It was considered very low; in fact, it is comparable to some of the estimates for exposures due to the TMI accident which released a very small amount of radioactive material compared to that expected to be released in the event of containment failure after a core melt accident.

- The Atomic Industrial Forum (AIF) is also actively involved in developing the use of probabilistic risk assessment (PRA) in the regulatory process (AIF, 1980; 1980a). They have proposed that PRA should support, not supplant, the current deterministic requirements and be used to suggest and justify changes in those requirements. Its use then would be as a basis for generic requirements and not, under present conditions, as a licensing condition for construction permit or operating license applicants. A common PRA methodology would be developed so that the PRA could be done as realistically as possible, with the degree of uncertainty and conservatism explicitly stated. Finally, quantitative safety goals would have to be established for PRA-based decision making. The AIF proposal is outlined below.

Basic principles for safety goals

- The goals should be generally applicable to all technologies or risk related activities.
- Acceptable societal risk should reflect societal benefits.
- No individual should bear an inordinate share of the risks.
- The goals should promote optimum allocation of resources in reducing risk.

Elements to be addressed in quantitative safety goals

- Individual health effects.

The incremental risk of adverse health effects to the maximally exposed individual in the vicinity of a nuclear power plant site should not result in a significant increase in annual mortality risk or in significant shortening of statistical life span. The suggested goal was an incremental individual mortality risk of 10^{-5}/year. This is a small fraction of existing background risk due to all causes (~ 0.1% of the total mortality risk and ~ 1% of the accident mortality risk).

- Population health effects.

The incremental cumulative risk of adverse health effects to the exposed population per 1000 MW(e) of nuclear power capacity, considering the probability and consequences of events integrated over the spectrum of potential accidents, should be no more than a small fraction of the average background incidence of health effects. The suggested goal was 0.1 fatality per 1000 MW(e) year. This represents about 0.001% of the total mortality risk and about 0.005% of the total cancer risk, assuming a total nuclear capacity of 200,000 MW(e).

- Cost benefit ratio

The benefit, in terms of population risk reduction, afforded by a change in plant design or operating procedure should be comparable to that which is generally achievable through alternative investments of the cost of the change in other areas of public risk reduction. The suggested goal was $100/man-rem. This was stated to be equivalent to $1 million/life saved and comparable to the median cost-benefit ratios for other health and safety protective measures.

- Core degradation probability

A limit should be established for the probability of accidents involving serious core degradation such that, given the expected population of reactors, the recurrence interval for accidents as

> serious at the one at Three Mile Island would be on the order of one per several decades. This would establish minimum re-requirements for accident prevention and is intended to prevent undue emphasis on mitigation of accidents. It would also reduce the frequency of stress provoking events for populations near plants and limit the economic risks of accidents.

The AIF suggested that the initial set of values should be used on an interim basis for a trial period of three years. It was also recognized that it is important for qualitative judgement to supplement the quantitative goals, particularly in borderline cases.

1.3.4 Observations

The ten quantitative risk proposals reviewed above demonstrate the effect of overall safety philosophy and policy on the choice of framework and the numbers used for the various categories of risk. Concern over community losses has led to limits on the total number of fatalities (for example, Farmer, 1967; Kinchin, 1979; CIRIA, 1977, Okrent and Whipple, 1977; AIF, 1980) while other proposals are only concerned with individual risks (Adams and Stone, 1967; Bowen, 1975; AECB, 1978; Comar, 1979). Of those that address community risks, some considered a large scale accident (or catastrophe) more costly than many accidents resulting in the same number of fatalities, while others set limits only on the expected number of fatalities averaged over time. Given these variations in items considered important for safety regulation, it becomes clear that comparisons with the risks of alternate technologies will not be straightforward.

It should be noted that the criteria discussed above have dealt directly only with public health and safety issues. Any complete risk management framework must also consider property damage and threats to important resources such as forests, farmland and major aquifers.

1.4 Some Problems in the Use of Quantitative Safety Goals

Several sets of problems have to be adddressed if quantitative safety goals are to be used to improve the management of risk. They arise in the establishment of the goals, in the achievement of compliance with the goals, and in the demonstration of that compliance.

1.4.1 Establishing the Safety Goals

As discussed earlier, safety impacts are one of several sets of impacts that are considered in the multilevel decision whether to build a particular facility at a particular site. A quantitative risk management framework must be compatible with all aspects of the decision and impact considerations.

Much of the concern over the use of cost and risk-benefit assessment is due to its lack of completeness and its sensitivity to the assumptions used in the analyses, which are not always clearly stated in the presentation of results. One of the fears is that a single number, which is both uncertain and based upon tenuous assumptions, will be used to make decisions. Also, some broader philosophical problems arise. Harold Green (1975) has said that "the question is whether safety determinations of public policy import are, or should be solely within the province of any single discipline or whether they should reflect the collective wisdom of an amalgam of disciplines or viewpoints, expert as well as non-expert." He recommended that the analysts should make their results open and understandable, with the assumptions and uncertainties stated clearly, and that the analysis should be used as input to the decision process and not as a substitute for it. Reliance on a single number would not allow for a grey scale and would obscure more subtle issues (Green, 1975a). In light of these concerns, a workable risk management framework would have to be a synthesis of many viewpoints, would have to consider many aspects of risk and the various tradeoffs, and would have to deal explicitly with uncertainties.

It is noted that the Advisory Committee on Reactor Safeguards in its letter of May 16, 1979 to the NRC, in which it recommended that the NRC develop quantitative safety goals, also recommended that "Congress be asked to express its views on the suitability of such goals and criteria in relation to other relevant aspects of our technological society..." (ACRS, 1979).

1.4.2 Uncertainties

Important uncertainties in the management of risk arise both in the estimation of the types and magnitude of all the impacts and in the prediction of the effects upon those impacts of various interacting policy options. Many important impacts may be left out and the assignment of a common measure of cost to the impacts that are included is not possible without controversy.

In the analysis of accidents both the frequency of each accident scenario and its consequence are uncertain. Some of the uncertainty is due to the randomness in the initiation of the possible accident sequences and therefore in the conditions internal and external to the facility at the beginning of the accident. The risk analysis is an attempt to estimate the distribution of the frequency and consequences of these accidents. However, the estimates of the distributions are also very uncertain. This uncertainty is due to inadequacies in failure rate data for the plant components, to shortcomings in the models of the plant systems and in the models of the emergency plans; and it is also due to possible ommissions from the analysis.

A proper risk assessment would explicitly estimate the range and types of uncertainty. However, there will always be a lack of assurance about the estimates of low frequency, high consequence events, because comparison with historical data is not possible.

1.4.3 Bias and Abuse

While the analyst may attempt to make calculations in the risk assessment objective, a large amount of subjective judgement is involved in the choice of models, in the selection of data, and in the assessment of the adequacy of the large number of often subtle assumptions that are incorporated into the analysis (Van Horn and Wilson, 1976). At present, methods for some aspects of the risk analysis are just being developed, e.g., treatment of fires and earthquakes, and may lead to cursory or distorted results. The subjectivity, the subtlety and the novelty leave analysis open to bias which is unintended, as well as to outright abuse. For these reasons, measures for quality assurance in the methods and performance of the analysis should be developed and peer review should be required.

1.4.4 Conflict

The variation of both societal values and societal risks, as well as the uncertainties in the estimation of those risks, ensures that there will always be conflict in the management of risk. While the adversary nature of the decision process allows for each side to be heard and makes possible a better decision, there will never be complete consensus on all of the issues whenever society imposes risks on a particular group, even if it is for the overall good of society.

After the form and the numbers of a management framework have been established, there should be a clear straightforward method to decide whether the criteria have been met. The conflicts then, might logically be separated into questions of goal setting and goal achievement. The risk management framework itself will be the result of the resolution of the first set of questions and it must provide a means of resolving the second set of questions in the presence of uncertainties and even without consensus, so that the improvements in the decision are not overshadowed by the costs of the conflict and the associated delay.

1.5 References

ACRS, (1979), letter from M. W. Carbon to J. M. Hendrie, 16 May, 1979.

Adams, C.A. and C.N. Stone, (1967) "Safety and Siting of Nuclear Power Stations in the United Kingdom," IAEA Symposium on the Containment and Siting of Nuclear Power Plants, Vienna, April 1967.

AECB, (1978) "Proposed Safety Requirements for Licensing of CANDU Nuclear Power Plants," Report of the Inter-Organizational Working Group, Atomic Energy Control Board, Canada, AECB-1149, November 1978.

AIF, (1980), "Statement on the Use of Probabilistic Risk Assessment in the Regulatory Process," Atomic Industrial Forum Committee on Reactor Licensing and Safety, June 1980.

AIF, (1980a), Atomic Industrial Forum Presentation before the Advisory Committee on Reactor Safeguards, USNRC, July 1, 1980.

Baram, M.S., (1980), "Cost-Benefit Analysis: An Inadequate Basis for Health, Safety, and Environmental Regulatory Decisionmaking," Ecology Law Quarterly, 8, pp. 473-531, 1980.

Beattie, J.R., G.D. Bell and J. E. Edwards, (1969), "Methods for the Evaluation of Risk," UKHEA Report AH SB(s) R 159, U.K. Atomic Energy Authority (1969).

Black, B., F. Niehaus and D. Simpson, (1979), How Safe is Too Safe?, International Institute for Applied Systems Analysis, WP-79-68, June 1979.

Bodansky, D. and F.H. Schmidt, (1979), "The Nuclear Alternative," Mercer Law Review, Walter F. George, School of Law, 30(2) pp. 395-444, 1979.

Bowen, J., (1975), "The Choice of Criteria for Individual Risk, for Statistical Risk, and for Public Risk," in D. Okrent (ed.), Risk-Benefit Methodology and Application: Some Papers Presented at the Engineering Foundation Workshop, September 22-26, 1975, Asilomar, California, School of Engineering and Applied Science, University of California, Los Angeles, UCLA-ENG-7598, pp. 581-590, 1975.

CIRIA, (1977), Rationalization of Safety and Serviceability Factors in Structural Codes, Construction Industry Research and Information Association, London, Report 63, July 1977.

Cohen, B.L., (1980), "Society's Valuation of Life Saving in Radiation Protection and Other Contexts," Health Physics, 38, pp. 33-51, 1980.

Comar, C.L., (1979), "Risk: A Pragmatic De Minimis Approach," Science, 203, p. 319, 1979.

Farmer, F.R., (1967), "Siting Criteria--A New Approach," Containment and Siting of Nuclear Power Plants, Vienna: International Atomic Energy Agency, pp. 303-318, 1967.

Farmer, F.R. and J.R. Beattie, (1976), "Nuclear Power Reactors and the Evaluation of Population Hazard," Adv. Nucl. Sci. Tech., 9, pp. 1-72, 1976.

Fischhoff, B., C. Hohenemser, R.E. Kasperson and R.W. Kates, (1978), "Handling Hazards: Can Hazard Management be Improved?," Environment, 20(7), pp. 16-37.

Fischhoff, B., P. Slovic and S. Lichtenstein, (1979), "Weighing the Risks (Acceptable Risk), Environment, 21, pp. 17-38, 1979.

Fishchoff, B., S. Lichenstein, P. Slovic, S. Derby and R. Keeney, (1980) "Approaches to Acceptable Risk," a report being prepared under contract to the U.S. Nuclear Regulatory Commission, 1980.

Green, H.P., (1975), "The Risk-Benefit Calculus in Safety Determinations," George Washington Law Review, 43(3), pp. 791-807, 1975.

Green, H.P., (1975a). "Legal and Political Dimensions of Risk-Benefit Methodology," in D. Okrent (Ed), Risk Benefit Methodology and Applications: Some Papers Presented at the Engineering Foundation Workshop. September 22-26, 1975, Asilomar, California, University of California, Los Angeles, UCLA-ENG-7598, pp. 273-290. 1975.

Hershey, J.C. and P.J.H Schoemaker, (1980), "Risk Taking and Problem Context in the Domain of Losses: An Expected Utility Analysis," J. of Risk and Insurance, 57(1), pp. 111-132, 1980.

Kinchin, G.H., (1978), "Assessment of Hazards in Engineering Work," Proc. Instn. Civ. Engrs., 64, pt. 1, pp. 431-438, 1978.

Kinchin, G.H., (1979), "Design Criteria, Concepts and Features Important to Safety and Licensing," Proc. of Inter. Meeting on Fast Reactor Safety Technology, Seattle, Washington, 1979.

Litai, D., (1980), A Risk Comparison Methodology for the Assessment of Acceptable Risk, Ph.D., Thesis, Massachusetts Institute of Technology, January 1980.

Lowrance, W.W., (1976), Of Acceptable Risk: Science and the Determination of Safety, Kaufman, Los Altos, 1976.

NSAC, (1980), "A Proposed National Nuclear Safety Goal," Nuclear Safety Analysis Center, Electric Power Research Institute, March 1980.

NSAC, (1980a), Nuclear Safety Analysis Center presentation before the Advisory Committee on Reactor Safeguards, USNRC, July 1, 1980.

Okrent, D., (1977), A General Evaluation Approach to Risk-Benefit for Large Technological Systems and its Application to Nuclear Power, School of Engineering and Applied Science, University of California, Los Angeles, UCLA-ENG-7777, December 1977.

Okrent, D. and C. Whipple, (1977), An Approach to Societal Risk Acceptance Criteria and Risk Management, School of Engineering and Applied Science, University of California, Los Angeles, UCLA-ENG-7746, June 1977.

Otway, (1977), "Risk Assessment and the Social Response to Nuclear Power," J. Br. Nucl. Energy Soc., 16(4), pp. 327-333, 1977.

Otway, H.J., (1978), "An Interdisciplinary Approach to the Management of Technological Risks," Advanced Seminar of Risk and Safety Assessment in Industrial Activities, Commission of the European Communities, Ispra, Italy, June 1978.

Plott, C., (1978), "On the Incorporation of Public Attitudes Toward Administrative Options," Risk/Benefit Decisions and the Public Health, 3rd FDA Science Symposium, USAF Academy, Colorada Springs, pp. 38-47, 1978.

Rasmussen, N., (1978/79), "Setting Sensible Safety Criteria," Colloquium on Risks, NUS Corporation, Rockville, Maryland, Winter 1978/79.

Rowe, W.D., (1977), An Anatomy of Risk, Wiley, New York, 1977.

Schwing, R.C., (1979), "Longevity Benefits and Costs of Reducing Various Risks," Technological Forecasting and Social Change, 13, pp. 333-345, 1979.

Siddall, E., (1979), Nuclear Energy in Perspective, CANATOM, Ontario, 1979.

Slovic, P., B. Fischhoff and S. Lichtenstein, (1980), "Perceived Risk," R.C. Schwing and W.H. Albers, Jr., (Eds), Societal Risk Assessment: How Safe is Safe Enough?," New York: Plenum Press, 1980.

Starr, C., (1969), "Social Benefit Versus Technological Risk," Science, 165, pp. 1232-1238, 1969.

Starr, C. and C. Whipple, (1980), "Risk of Risk Decisions," Science, 208, pp. 1114-1119, 1980.

Van Horn, A.J. and R. Wilson, (1977), "The Status of Risk-Benefit Analysis," Energy and Environmental Policy Center, Harvard University, Cambridge, Massachusetts, December 1976.

2. RISK MANAGEMENT AND DECISION RULES FOR LIGHT WATER REACTORS

J. M. Griesmeyer and D. Okrent

2.1 Introduction

A central issue in energy policy is the controversy over the risks from various technologies to generate power. The conflict arises in the attempt to balance many types of risks and benefits and is deeply rooted in the variation of societal values used in making comparisons. The situation is further complicated by the large uncertainties involved in the estimation of risks and benefits. The cost of the conflicts to society is great and means need to be found to resolve some of the conflict and reduce its cost.

The safety philosophy used by the NRC, often called the "defense in depth" concept, has provided a substantial amount of guidance which is contained in the NRC rules and regulations and in NRC Staff documents dealing with the safety of nuclear power plants, such as regulatory guides and branch technical positions. However, since it is basically a risk reduction philosophy without fully articulated safety goals, it does not directly address the question: "How safe is safe enough?", nor does it quantify the residual risk which is implicitly being accepted.

The process of developing and adopting safety objectives in quantitative terms can provide a basis for focusing societal decision making on the suitability of such objectives and upon questions of compliance with those objectives. A preliminary proposal for a light water reactor (LWR) risk management framework is presented here as part of that process.

Although an extended philosophical background is not presented, the basic rationale behind the form and the components of the framework is given. The preliminary numerical values suggested for use in the framework are intended to ensure adequate protection of public health and safety and the environment. While plausibility arguments are given for some of the numerical values, they are all primarily a matter of judgment. At this early stage in the development of quantitative safety goals, the structure of the risk management framework is more important than the numerical values assigned to specific parameters. However, we believe that it is useful and perhaps necessary to have at least a range of possible numerical values in mind to help stimulate discussion and evaluation in concrete terms.

Ultimately, the NRC and the Congress must consider a wide range of socio-political and economic factors, of which direct risk to the public health and safety is but one, in arriving at a judgment on suitable risk acceptance levels for nuclear reactors.

The risks that arise from the mining and processing of fuel and the disposal of wastes must also be managed. However, these additional parts of the fuel cycle are separate undertakings from the reactor itself and are not addressed here. Occupational risks to reactor plant personnel are also not addressed herein.

Risk management in this proposal is divided into two major tasks: the predominantly social and political task of setting the safety goals and the technical task of estimating the risks and deciding whether the safety goals have actually been met.

The safety goals are expressed in the form of a set of quantitative decision rules which include:

- Limits placed on the frequency of occurrence of certain hazardous conditions (hazard states) within the reactor
- Limits placed on the risk of the individual of early death, or delayed death due to cancer arising from an accident
- Limits placed on the overall societal risk of early or delayed death
- An "as low as reasonably achievable" approach applied with a cost-effectiveness criterion that includes both economic costs and a monetized value of preventing premature death

- A small element of risk aversion applied to infrequent accidents involving large numbers of early deaths compared to a similar number of deaths caused by accidents each involving one or two deaths.

Each decision rule on hazard states and on individual and societal risk consists of a pair of numbers: an upper, non-acceptance limit on risk and a lower, safety-goal level of risk. Compliance with the upper limit would be required for extended operation of the plant; otherwise, it must be improved within a certain period of time (to be determined) that depends upon the severity of the risk involved. On the other hand, any risk value lower than the safety-goal level would be considered in compliance for the particular category of risk. However, risks must be further reduced below these safety-goal levels whenever improvements are possible that meet certain cost effectiveness criteria for risk reduction. Between the upper non-acceptance limit and the lower safety-goal level of risk is a digressionary range in which case by case consideration of uncertainties, regional need for power, and alternative risks are required in the decision as to whether the plant should be allowed to operate for an extended time without modification.

The rest of the framework deals with the task of risk quantification. A major tool for this effort will be a plant and site specific quantitative risk analysis which is essentially a probabilistic estimate of the distribution of risks. The details of the analysis will form a safety profile of the particular plant and site that can be used to make risk-based decisions on design or procedural changes. The estimated risk distribution will explicitly express the range of uncertainties and will be used in the application of the decision rules. Special attention must be given to quality assurance of the risk assessment. There must be full and explicit identification of the assumptions and limitations of the analysis, and peer review will be required. In addition, it is proposed that a procedure be established to provide a legally binding determination of those risk distribution values to be used with the decision rules.

2.2 Decision Rules

The decision rules are comprised of a group of criteria intended to ensure adequate protection of public health and safety, property and the environment. They deal with hazardous conditions within the plant that are precursors to offsite risk, with individual and societal risk limits, and with societal risk reduction. The decision rules proposed herein are for new plants. Meeting these limits would be a necessary condition for consideration as an alternative to satisfy the need for power. Flexibility is built into the decision rules to allow for consideration of special cases; limits are placed upon various types of risk and take the form of an upper nonacceptance limit, a discretionary range, and a goal level of risk. Compliance with the upper limit in each category of risk is required. Within the discretionary range, the severity of the risk, uncertainties in risk estimation, competing risks, and the regional need for power are considered in marginal cases. Risk estimates below the goal level will be considered to be in compliance with the risk limit desired in the particular risk category. In addition to compliance with the risk limits, risk must be further reduced whenever improvements are possible that meet certain cost-effectiveness criteria.

The limits are meant to flag conditions judged tentatively not to be acceptably safe or only marginally so. While the current public attitudes may be such that society wants the limits on nuclear risks to be less than those set upon the risks of other technological options, the fact that the alternatives also impose risk upon society suggests that the limits should not be set so low as to render the nuclear option infeasible in situations where the alternatives may pose greater risks.

In the analysis of accidents, both the frequency of each accident scenario and its consequence are uncertain. Some of the uncertainty is due to the randomness in the initiation of possible accident sequences and in the conditions internal and external to the facility. The risk analysis is an attempt to estimate the distribution of frequency and consequences. However, there are uncertainties in the estimate due to a variety of reasons including the following: inadequacies in failure rate data for the plant components; shortcomings in models of plant systems and in the models of the emergency plans; the difficulty in analyzing certain scenarios such as sabotage; and possible errors and omissions from the analysis. The form of the decision rules is intended to compensate for some of this uncertainty. Limits are placed on the expected values of the various risks. These expected values are the weighted average of the probabilities and therefore reflect some of the uncertainties (e.g., the ratio of the expected value to the median value increases as the uncertainty increases). Also, limits are placed both on the frequency of a fuel damaging accident and on the risk of a large release of radioactive material assuming the occurrence of fuel damage, thereby requiring both prevention and mitigation.

The decision rules proposed herein are for new plants and may be more stringent, possibly by a factor of two or more, than is deemed appropriate for existing plants.

2.2.1 Hazard States

Although the primary aim of the NRC is to protect the public health and safety, accidents which damage the facility without a significant release of radioactive material offsite must also be addressed, partly because they represent possible forerunners of more severe accidents and partly because of public and utility economic losses, and because of the potential traumatic effect on the public. Hence, we have chosen to define a set of hazard states of progressive severity and to set limits on their rate of occurrence. Such an approach provides a structure for both accident prevention and accident mitigation.

An optimum set of hazard states and limits will take time to develop and test. The following set of hazard states of progressively increasing severity, each with a specific operational definition, is proposed on a tentative basis:

- Significant core damage (> 10% of noble gas inventory leaking into the primary coolant)
- Large scale fuel melt (> 30% of the oxide fuel becoming molten)
- Large scale uncontrolled release of radioactive material (>10% of the iodine inventory plus > 90% of the noble gas inventory) from the containment.

Table 2.1 summarizes the proposed decision rules concerning the hazard states. The basis for the limit on significant core damage is the goal that the frequency of occurrence for an accident of about the severity of the one at Three Mile Island should be less than one in 100 in a reactor lifetime. This places considerable emphasis on accident prevention and serves to reduce societal trauma and financial loss. The limit on fuel melt serves as a similar function. The limit on the frequency of a large off site release, assuming that a fuel melt has occurred, places emphasis on mitigation as well as prevention of serious accidents. Such a division between accident prevention and accident mitigation is believed to be necessary because of the difficulty in demonstrating with a very high degree of confidence that a

Table 2.1 Limits on Occurrence of Hazard States

Hazard State	Probability Goal	Decision Rules on Mean Frequency	
		Goal Level	Upper Limit
Significant Core Damage (> 10% of noble gas inventory leaking into primary coolant)	Less than 1/100 per reactor lifetime	$f_{cd} < 3x10^{-4}$ per reactor year	$f_{cd} < 1x10^{-3}$ per reactor year
Large Scale Fuel Melt - LSFM (> 30% of oxide fuel becoming molten)	Less than 1/300 per reactor lifetime	$f_m < 1x10^{-4}$ per reactor year	$f_m < 5x10^{-4}$ per reactor year
Large Scale Uncontrolled Release from Containment given LSFM (> 10% of Iodine inventory and 90% of noble gas)	Small, given a Large Scale Fuel Melt	$f_{R/m} < 0.01$ per LSFM	$f_{R/m} < 0.1$ per LSFM

f_{cd} is the frequency of Significant Core Damage per reactor year.

f_m is the frequency of Large Scale Fuel Melt per reactor year.

$f_{R/m}$ is the frequency of Large Scale Uncontrolled Release per Large Scale Fuel Melt.

The upper non-acceptance limits must be satisfied for extended operation of a new plant or for issuance of a construction permit. Between the upper limits and the goal levels is a discretionary range for case-by-case consideration of uncertainties and competing risk. Once the risk level decision rules have been applied, risk must still be reduced if such reduction is reasonably achievable within the cost-effectiveness criterion of Table 2.4.

frequency of large scale fuel melt much less than the proposed goal of 10^{-4} per reactor-year can be achieved in view of the complexities introduced by consideration of matters such as sabotage, earthquakes, and other potential multiple failure scenarios.

2.2.2 Individual Risks

Equity considerations naturally lead to the notion that an individual should not be unduly burdened by risk. However, the definition of undue risk is complicated by consideration of the risks due to the alternatives and by controversies over the evaluation of different types of risk.

Individual health and safety risks posed by the light water reactor (LWR) include early death and illness, fatal and nonfatal cancers, and genetic effects. It is presumed here that control of early deaths and latent cancer deaths will adequately control the other effects as well. For the purposes of the decision rules, we consider the generation of electricity to be an activity important to society and set the limits below background risks or those from the principal competing source.

In the United States, girls 10-14 years of age have the smallest death rate, approximately 10^{-4} per year, which is due primarily to accidents. This mortality rate is typical of many occupational risks, and is about two orders of magnitude greater than that posed by risk situations that are normally considered negligible (e.g., lightning). The average death rate for the entire U.S. population is about 10^{-2} per year.

A one-in-two-thousand chance (0.0005) over an individual's lifetime that the reactors at a particular site will be the cause of the individual's death due to cancer, corresponds to a yearly risk of induction of fatal cancer of about 10^{-5} per year. Since the power generated by a plant is generally beneficial to society, it is suggested here that a one-in-two-thousand risk of fatal cancer over one's lifetime due to reactors is a plausible goal level. This compares with a background risk of death by cancer due to all causes of 0.15 to 0.2.

Various methods have been suggested for assigning a weighting factor between delayed cancer death and early death. If the severity of risk is represented by the associated loss in life expectancy, an early death in which all remaining life expectancy is lost would, on the average, be two to three times worse than a delayed cancer death. On the other hand, some studies in the literature have arrived at a factor as high as thirty for the greater importance of early death compared to delayed death by analyzing historical data (Litai, 1980) or by noting that death within one year seems much worse than death ten to fifteen years from the present. In the current proposal, a factor of five is used between the limit on the risk of delayed cancer death and the limit on the risk of early death.

Table 2.2 summarizes the proposed decision rules for risks of delayed cancer death and of early death to the most exposed "average" individuals.* Note that only a few people will have risks as high as the most exposed individuals who presumably reside close to the plant site boundaries. Most people will be exposed to risks lower than the goal levels.

The limits on the risk of death, assuming that a large-scale fuel melt accident has occurred, require that special attention be given to mitigation of an accident and to offsite emergency plans. Indeed, by inspection of Tables 2.1 and 2.2 it is found that, if both the goal level for fuel melt and the goal levels for individual risk of delayed or early death, given a fuel melt, are met, then the product gives risks of delayed and early death a factor of five less than the goal levels of individual risk. If only upper limit on both fuel melt and individual risk, given fuel melt, are satisfied, then the individual risks found from the product of fuel melt frequency and risk, given fuel melt, are still below the upper limit on individual risks.

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*For the purpose of applying the decision rules, the estimated radiation dose to the most exposed individual will be found using realistic models including possible emergency plans. This will be done for all significant accident scenarios. The "average" individual will be operationally defined as an individual whose response to the dose is the same as the dose response averaged over a represenative distribution of the population.

Table 2.2 Limits on Risks to Most Exposed Individual

Probability Goal	Mean Frequency per Site-year		Decision Rules on Mean Frequecy per Large Scale Fuel Melt-LSFM	
	Goal Level	Upper Limit	Goal Level	Upper Limit
Probability of delayed death from cancer due to all reactors at a site over lifetime of individual <0.0005	$f_d < 5 \times 10^{-6}$ per site-year	$f_d < 2.5 \times 10^{-5}$ per site-year	$f_{d/m} < 0.01$ per LSFM	$f_{d/m} < 0.05$ per LSFM
Probability of early death due to a reactor accident over lifetime of individual < 0.0001	$f_{ed} < 1 \times 10^{-6}$ per site-year	$f_{ed} < 5 \times 10^{-6}$ per site-year	$f_{ed/m} < 0.002$ per LSFM	$f_{ed/m} < 0.01$ per LSFM

f_d	is the individual risk of delayed cancer death per site year.
$f_{d/m}$	is the individual risk of delayed cancer death per large scale fuel melt.
f_{ed}	is the individual risk of early death per site year.
$f_{ed/m}$	is the individual risk of early death per large scale fuel melt.

The upper non-acceptance limits must be satisfied for extended operation of a new plant or for issuance of a construction permit. Between the upper limits and the goal levels is a discretionary range for case by case consideration of uncertainties and competing risks. Once the risk level decision rules have been applied, risk must still be reduced if such reduction is reasonably achievable within the cost-effectiveness criteria of Table 2.4.

This overlapping of requirements is intended to ensure that the individual risks are small even if omissions from the analysis cause underestimation of various risk components. It also provides details that will be relevant in the case by case consideration of risks that are estimated to be above the goal levels but below the upper limits.

The intention here is to put an upper limit on individual risks due to LWRs and ensure that the most significant individual risk arises from elsewhere in the environment. The proposed limits may actually be too low when one considers what is achievable by the major alternative technologies to generate electricity or when one considers other major political and economic factors.

2.2.3 Societal Impacts

The aggregate societal public health and safety and environmental risks due to an LWR are just part of the costs which are crudely balanced with benefits and other socio-political factors in the decision to build an LWR. Because of the societal trauma and other secondary impacts that affect societal resilience in the event of a catastrophe, the societal cost of a single large accident may be greater than that of a large number of smaller accidents which , in the aggregate, kill the same number of people or cause the same amount of property or environmental damage.

A related problem arises when assessing the risks due to low frequency high consequence events if the frequency is so low that it is very unlikely for the event to occur during the lifetime of a particular facility or even a large number of facilities. In this case, presentation of the risk only in terms of the expected risk (frequency times consequence) simultaneoulsy overestimates the costs that must be absorbed by society in the normal year but obscures the threat of a major catastrophe.

The decision rules for the management of societal impacts in the current proposal are separated into two major groups. The first group sets limits on societal risks and, as in the case for the hazard states and individual risks, compliance with these limits would be a necessary condition for the plant to be considered as an alternative to supply the needed electricity or for extended operation of a new plant. The second group of decision rules uses an "as low as reasonably achievable" cost-effectivness criterion to judge whether additional risk reduction is required beyond that level of safety required to meet the other decision rules.

2.2.3.1 Public Health and Safety Impact Limits

In the case of societal health risks it is assumed that the control of both early and delayed deaths will adequately control other effects, and the limits are placed accordingly. Societal benefits can be crudely measured by the amount of electricity generated, and we have chosen to express the limits in terms of 10^{10} kilowatt-hour (kWh). This corresponds to the output of a 1200 megawatt electric plant operating at full capacity for one year or that of a 1000 megawatt electric plant operating at 75% capacity for about 1.5 years.

It has been suggested in the literature that society is risk averse when comparing a single infrequent large accident with a number of small accidents leading to the same total number of fatalities in the same time period. A simple approach which assesses an equivalent social cost that increases faster than the actual consequences for events involving multiple deaths uses an equation of the form

$$\text{Equivalent social cost} = \sum_{\text{accidents}} (\text{Frequency})(\text{Consequence})^{\alpha}.$$

in which α is greater than unity. If α is equal to one, the equivalent social cost would be the same as the expected cost (frequency times consequence). Although values of α as high as 2 or 3 have been proposed in the literature for fatalities from accidents, such values would prohibit many existing technological endeavors because of the extremely high equivalent social cost, (e.g., dams or large quantities of hazardous chemicals stored close to population centers). We do not believe society is consciously placing such high risk aversion penalties on needed activities, nor that it can afford to (Griesmeyer, Simpson, and Okrent, 1979).

In this proposal it is suggested that the social cost for delayed cancer deaths should be assessed as equal to the expected number of fatalities (i.e., $\alpha = 1$). The range on the estimated number of people who die from the pollution arising from a coal-fired plant which generates 10^{10} kWh is about 10 to 200 (Hamilton and Manne, 1978); 10 per 10^{10} kWh is proposed here as the upper, nonacceptance limit on the delayed cancer deaths due to a nuclear power plant; the goal level is that there be less than two cancer fatalities per 10^{10} kWh.

To provide incentives to reduce the catastrophic potential of accidents, we tentatively choose to assess the equivalent social cost of early deaths using $\alpha = 1.2$; hence the equivalent early death cost of the plant, E_{ed}, would take the form

$$E_{ed} = \sum_{\text{accidents}} (\text{Frequency})\ (\text{Early Deaths})^{1.2}$$

The limits on equivalent early deaths are reduced by the same factor of five from the delayed cancer death limits as was done for the limits on individual risk. Table 2.3 summarizes the decision rules for societal health risks.

2.2.3.2 Property and Resource Damage

In addition to public health and safety risks, large scale land and water contamination are important potential hazards associated with an LWR. The available information of a site specific nature is not in sufficient depth to assess fully the impacts of a fuel melt accident on water resources or land use, and its potential effect on future siting policies or reactor design requirements. More study of the potential nature of the land contamination problem, its effects, and

Table 2.3 Societal Health Risk Limits

Measure of Risk	Decision Rules on Societal Health Risks	
	Goal Level	Upper Non-Acceptance Limit
E_d = the expected value of: $\sum\limits_{\substack{\text{accidents}\\\text{and normal operation}}}$ (Frequency) (Delayed Cancer Deaths)	$E_d < 2$ per 10^{10} kWh	$E_d < 10$ per 10^{10} kWh
E_{ed} = the expected value of: $\sum\limits_{\text{accidents}}$ (Frequency) (Early Deaths)$^{1.2}$	$E_{ed} < 0.4$ per 10^{10} kWh	$E_{ed} < 2$ per 10^{10} kWh

E_d is the average number of delayed cancer deaths per 10^{10} kWh of electricity generated.

E_{ed} is the average number of equivalent early deaths per 10^{10} kWh of electricity generated.

10^{10} kWh is the amount of electricity generated by a large (1200 MWe) power plant operating at full capacity for one year.

The upper non-acceptance limits must be met for extended operation of a new plant or for issuance of a construction permit. Between the upper limits and the goal levels is a discretionary range for case by case consideration of uncertainties and competing risk. Once the risk level decision rules have been applied, risk must still be reduced if such reduction is reasonably achievable within the cost-effectiveness criteria of Table 2.4.

possible means of dealing with it, including remuneration for financial loss, appears to be needed. For example, the effect of the release of a substantial amount of radioactive material on a specially fertile and productive farm area must be considered. Some insight into the impact of loss of resources may be obtained by examination of the recent Kepone incident in Virginia and the eruption of Mt. St. Helens in Washington.

A risk management framework should address these issues, but the development of measures of these risks has not been completed, and sound rationales for specific limits, if any, on such risks remain to be proposed. Economic measures of environmental risks usually include only damage that has direct health and economic effects. However, there is the unquantified (at this time) damage to the environment's ability to absorb pollutants and provide life support. It is possible that these risks are at least as significant as the direct health risks for some technologies (e.g., the effects of the acid rain from the burning of fossil fuels).

It may be possible to estimate the social cost of certain types of resource damage. However, these estimates must properly treat low frequency-high consequence events and reflect the fact that marginal replacement costs are not adequate when the losses are large.

With respect to quantitative limits on economic losses, it may only be feasible to identify important resources that need special attention such as major aquifers and productive farmland and, beyond some threshold level of adverse effect, to require special consideration in licensing. We do not propose any limits on economic losses in these decision rules. Resource damage is included, however, in the proposed measures for societal impact reduction discussed in the next section.

2.2.4 Societal Impact Reduction - ALARA

Compliance with the risk limit decision rules will help assure that nuclear power plants do not pose undue risk to society when compared to the alternative means of generating electricity. Balancing of risk and benefits can only be done very crudely; hence, after the limits have been met, it is proposed that the risk be further reduced to the lowest reasonably achievable levels. Depending upon the feasibility of risk improvements, this requirement will determine the actual residual risk of a particular facility.

We propose to use an "as low as reasonably achievable" (ALARA) cost-effectiveness criterion to judge whether additional risk reduction is required beyond that level of safety required to meet the other decision rules. The cost of an improvement would be balanced against the combined change in economic losses and in the risks of delayed cancer deaths and equivalent early deaths.

While there is some limit on how much the United States can afford to spend to reduce risk from all of its technological activities, lest economic instability lead to greater risk directly or indirectly, the current perspective on nuclear reactor may be such that society is willing to spend more for LWR safety than for many other things. When cost-effectiveness considerations are employed, the marginal cost limit on expenditure for reducing single fatality risks used by various Government agencies ranges from about $0.1 million per death averted by the U.S. Department of Transportation, $0.2 to $2 million per death averted for various analyses by the Consumer Product Safety Commission and up to roughly $5 million in the NRC application of ALARA to routine release of radioactive material (Baram, 1980). A much wider range is implied if one looks at regulatory requirements that were implemented without direct consideration of cost-effectiveness (Cohen, 1980). It is tentatively proposed that the marginal cost limit on expenditures be set at $1 million per delayed cancer death averted and $5 million per equivalent early death averted, when "equivalent" deaths are calculated using the coefficient $\alpha=1.2$ for risk aversion. These high limits are chosen because of the special public concern over radiation risks.

It is anticipated that careful study will be required to quantify the economic losses due to property and resource damage. In order to stress prevention rather than repair of possible damages, and because of uncertainties and the fact that some impacts cannot be quantified, it is proposed that the marginal cost limit on expenditures to reduce adverse economic impacts be twice the expected reduction in impact when applying the ALARA criterion.

Table 2.4 summarizes the quantified ALARA criterion.

2.3 Risk Quantification

The discussion on risk quantification is divided into three sections: a description of the probabilistic safety profile, requirements for quality assurance in probabilistic analysis, and a risk certification procedure.

2.3.1 Probabilistic Safety Profiles

The decision rules will only be of use if they are part of a management framework that quantifies and systematically attempts to reduce risk and assure quality in plant design and operations. A comprehensive, detailed probabilistic risk assessment or safety profile for each particular plant and site could be a major tool for the management of risk. In this proposal, such a profile is required in order to provide the risk estimates to be used in the application of the decision rules. Uncertainties must be included explicitly in the risk profile. The analysis would be updated in accordance with operating experience and be modified as needed to deal with any new issues that arise.

The safety profile should actually have at least three major uses: the first would be as a design tool to improve plant reliability and to identify risk contributors for the particular plant at its site and suggest ways of cost-effective risk reduction. The second major use would be as a monitor to guide operations and maintenance. The final use would be as a licensing tool for application of the decision rules described above.

Table 2.4 Quantified ALARA Cost-Effectiveness Criteria

Expenditure Limits for Impact Reduction	
$1 million per delayed cancer death averted	$\$1 \times 10^6/(\Delta E_d\ L)$
$5 million per early equivalent death averted	$\$5 \times 10^6/(\Delta E_{ed}\ L)$
2 times the economic loss (due to resource damage) averted	$2/(\Delta E_r\ L)$
A particular improvement is "cost-effective" and required if $\text{Cost} \le [\ 2\Delta E_r + (\$5\text{x}10^6)(\Delta E_{ed}) + (\$1\text{x}10^6)(\Delta E_d)]\ L$	

ΔE_d is the change (due to the proposed improvements) in the expected value of:

$$\sum_{\substack{\text{accidents}\\ \text{and}\\ \text{normal}\\ \text{operation}}} (\text{Frequency})(\text{Delayed Cancer Deaths})$$

ΔE_{ed} is the change (due to the proposed improvements) in the expected value of:

$$\sum_{\text{accidents}} (\text{Frequency})\ (\text{Early Deaths})^{1.2}$$

ΔE_r is the change (due to the proposed improvements) in the expected value of:

$$\sum_{\text{accidents}} (\text{Frequency})\ (\text{Economic Losses})$$

L is the remaining lifetime of the plant in units of 10^{10} kWh to be gen and the frequencies are calculated per 10^{10} kWh. This is the amount of tricity generated by a large (1200 MWe) plant operating at full capacit one year.

2.3.2 Preparation, Review and Maintenance of the Safety Profile

Much of the methodology used in probabilistic safety analysis is relatively new and, as such, two major problems must be addressed. The first is the lack of qualified practitioners and the second is the controversy that still exists regarding the use and interpretation of the methods. The development of quality assurance criteria for probabilistic analysis to be used in nuclear reactor licensing will be required.

It is proposed that the NRC have the responsibility for evaluating methodologies and results provided by the reactor owner, and also to arrange for a third party review of the probabilistic risk assessments.

An engineering safety group within the licensee organization would have the ultimate responsibility for the development, use, and maintenance of the safety profile, although original preparation will have to be directed or attested to by the equivalent of a well qualified professional engineer whose speciality is nuclear reliability, safety and risk assessment. The engineering safety group would investigate the impacts of new issues and operations experience with reference to the safety profile.

2.3.3 Certification of Results

The large uncertainties inherent in the calculation of risk from rare events makes it impractical to achieve universal agreement on the quantitative results, and one must anticipate continuing disputes between the licensee, the NRC Staff, and others regarding the quantitative levels of risk. The actual set of decision rules would have been chosen through a political process which considers questions of risk acceptance. However, in order to implement the decision rules, a legally binding method must be developed to provide closure on the question of the risk distribution estimates to be used with the decision rules.

A possible approach to this problem would be to establish a Risk Certification Panel. After the third party peer review of the analysis arranged by the NRC had been completed, the panel would be given the statutory authority to make a legally binding determination of those risk distribution values to be used in the application of the decision rules. The panel may or may not be independent of the NRC. However, if it is established within the NRC, it should be separated from the licensing staff who would be making decisions with reference to application of the decision rules.

It is hoped that the proposed framework will stimulate discussion and help in the process of developing and adopting safety objectives in quantitative terms.

2.4 References

Baram, M.S., (1980), "Cost-Benefit Analysis: An Inadequate Basis for Health, Safety, and Environmental Regulatory Decisionmaking," Ecology Law Quarterly, 8, pp. 473-531, 1980.

Cohen, B.L., (1980), "Society's Valuation of Life Saving in Radiation Protection and Other Contexts," Health Physics, 38, pp. 33-51, 1980.

Griesmeyer, J.M., M. Simpson and D. Okrent, (1979), The Use of Risk Aversion in Risk Acceptance Criteria, School of Engineering and Applied Science, University of California, Los Angeles, UCLA-ENG-7970, October 1979.

Hamilton, L.D. and A.S. Manne, (1978), "Health and Economic Costs of Alternative Energy Sources," IAEA Bulletin, 20(4), pp. 44-58, 1978.

Litai, D., (1980), A Risk Comparison Methodology for the Assessment of Acceptable Risk, Ph.D Thesis, Massachusetts Institute of Technology, January 1980.

3. APPLICATION AND IMPLICATIONS OF TRIAL RISK ACCEPTANCE CRITERIA

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3.1 Introduction

The formulation of quantitative safety goals or risk acceptance criteria requires an understanding of how such goals or criteria will be applied and what implications they would carry. Several forms of risk acceptance criteria have been proposed which not only represent diverse approaches but also would present a variety of implications if put into practice. These implications arise from such diverse considerations as the purpose of the criteria, the mode of their application, the treatment of equity and uncertainties, the application of risk aversion and As Low As Reasonably Achievable (ALARA) concepts, the characterization of consequences, and the adequacy of the framework to deal with dynamic demographic variables as well as delayed versus early health effects.

The objective of this paper is to investigate some of the implications inherent in the application of a trial set of risk acceptance criteria. To this end a simplified set of trial criteria is presented in Table 3.1.1. As may be noted, two levels of criteria are given: a goal level and an upper limit.

In addition a power-law model of risk aversion is utilized to estimate the equivalent number of individual deaths and is treated parametrically. The implications of ALARA requirements for cost-effective improvements are also illustrated. Individual and societal risk acceptance criteria together with mechanisms to address risk aversion and cost-effective considerations constitute a framework for risk management.

TABLE 3.1.1 TRIAL RISK CRITERIA

Type of Criteria	Suggested Value
Goal level (upper limit) for risk of delayed death to the most exposed individual	5×10^{-6} (2.5×10^{-5}) per site year
Goal level (upper limit) for risk of early death to the most exposed individual	1×10^{-6} (5×10^{-6}) per site year
Calculated expected value of the societal burden	10 deaths per site year

These trial criteria are not identical with those advanced in Part 2 of this report [1]. The justification for the differences lies in the reduced level of complexity required to undertake the present scoping study as well as the desired goal of applying the criteria to several technological endeavors. For example, risk limits are specified in units per site year (with one nuclear or coal-fired power plant per site), rather than per amount of energy generated, to facilitate a broad application of the criteria.

As indicated elsewhere [1], the proper application of risk acceptance criteria requires that special attention be paid to quality assurance in the risk analysis, including review and evaluation by well qualified practitioners as well as by independent peer groups. The necessary procedures, methodology and qualifications remain to be established, and few, if any, currently published risk analyses may have met this test. For this reason, the quantitative values discussed in this paper are not to be interpreted as strict estimates of risk; it is the risk acceptance framework that is of interest here.

The trial criteria are compared with the risks assessed for three technological endeavors; hypothetical nuclear power plants, hypothetical coal-fired power plants, and a multipurpose industrial complex. No critique of the referenced risk analyses is provided here.

The assessment of the risk associated with nuclear power is based primarily on follow-on work to the Reactor Safety Study (RSS). The individual risk of early death is estimated for the pressurized water reactor evaluated in the RSS scaled to a power level of 2895 MWt from data supplied by Sandia Laboratories. The individual risk of delayed death is estimated from information supplied by the NRC staff and was based on the RSS reactor. Societal risk estimates for both latent and early death are based on the RSS reactor, and on the RSS reactors scaled in size and placed, for example, on the Indian Point site* [2]. The effect of increasing the RSS risk estimates by a factor of 100 is also discussed.

The assessment of societal risks due to coal-fired power plants is based on a study performed at the Brookhaven National Laboratory [3] of four hypothetical 1000 MWe plants located near Pittsburgh. Health effects were correlated to the sulfate concentrations in the airborne effluents. Individual risks are estimated from societal risk estimates [3], as well as from a study of the implications of air quality standards [4].

In 1978 the Health and Safety Executive of the United Kingdom [5] completed an analysis of the risks associated with the Canvey Island industrial complex. The complex includes petroleum tank farms, LNG facilities, and oil refineries. Both individual and societal risks are estimated.

None of the risk assessments include all of the component risk contributors. The nuclear assessment involves primarily accident scenarios; the

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* The Indian Point site has the highest density neighboring population of any commercial nuclear power plant site in the U.S.

Canvey Island study exclusively so. On the other hand, the coal analyses consider only risks arising from normal operation. However, for the present purpose, these analyses are considered adequate for assessing the implications of the trial criteria.

3.2 Limits on Risk

3.2.1 Introduction

This section discusses some of the implications resulting from the application of the trial individual and societal risk criteria to the three technological endeavors previously mentioned: hypothetical nuclear power plants, hypothetical coal-fired power plants, and a multipurpose industrial complex. Further details on each of these are presented in Appendices A, B and C.

3.2.2 Limits on Individual Risk

Limits are placed on the measure of individual risk to ensure that no member of the public is unduly burdened by the endeavor under scrutiny. The trial criteria, by advancing limits on the individual risk that are small compared to the "background" risk of the statistically "safest" subgroup of the population (i.e., 10-14 year old females), attempt to address possible population age effects as well as equity. One alternative method of treating the equity concern would include the consideration of the benefits made available by the endeavor. Such a method, however, may result in increased difficulty in treating uncertainties in the analysis.

Ranges of point estimates of the individual risk for the case studies treated in Appendices A, B and C are shown in Table 3.2.1.

It should be noted that the estimates shown in Table 3.2.1 are not to be compared to one another. They should only be compared to the

TABLE 3.2.1* RANGE OF POINT ESTIMATES FOR INDIVIDUAL RISK

Technological Endeavor	Additional Annual Probability of Death to an Individual Near the Facility
Hypothetical nuclear power plant**	3×10^{-7} - 3×10^{-5} (early death from large accident)
Hypothetical coal-fired power plant***	1×10^{-5} - 2×10^{-4} (delayed death from normal operation)
Canvey Island industrial complex****	3×10^{-5} - 1×10^{-3} (early death from large accident)
Goal level (upper limit) for risk of early death as specified in Table 3.1.1	1×10^{-6} (5×10^{-6}) per site year
Goal level (upper limit) for risk of delayed death as specified in Table 3.1.1	5×10^{-6} (2.5×10^{-5}) per site year

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* These estimates are advanced for illustrative purposes only. Because of uncertainties and possible omissions in the analyses, no quantitative level of confidence is given for these estimates. The indicated ranges do not represent uncertainty bounds, but a range of point estimates. In addition, these estimates are not to be compared to one another, but should only be compared with the criteria.

** An estimate of the risk of early death due to an accident at a nuclear power plant, as represented by the hypothetical RSS PWR scaled to 2895 MWt, was based on a series of calculations performed at Sandia Laboratories which incorporated a simple evacuation model. Estimates of the risk of delayed death of an individual near a nuclear plant were based on analysis of the RSS reactor, as provided by the NRC Staff. This latter risk component, as assessed, was small compared to the risk of early death. Several simplifying approximations are involved in making this estimate, which may or may not have a net conservative effect; however, the upper limit on the range suggested simply indicates the effect on the above estimate for the hypothetical case of the accident sequences used in the RSS being low by a factor of 100. See Appendix A.

*** The estimated health effects from hypothetical coal-fired power plants are of a chronic nature and stem from normal operation. The range shown reflects independent assessments [3,4], however, larger values have also been estimated for the risk to the most exposed individuals. In addition, the values indicated are given per site year; because of the chronic nature of the releases, the health effects due to all surrounding plants should be considered. See Appendix B.

****The estimates of early death of an individual near the Canvey Island complex consider only accident scenarios. The range indicated reflects not only the specific location of the individual but also the degree to which improvements identified in the study are made. See Appendix C.

criteria. Difficulties exist if one attempts to make comparisons among the values. First, as previously indicated, the quantitative confidence levels of the estimates are unknown. Second, the nature of the impacts of the endeavors differs; the individual risk estimates from the hypothetical nuclear plant are dominated by early effects and those assessed from the Canvey Island facilities are exclusively for the early effects. The assessed impacts from the hypothetical coal plant are, in contrast, of a delayed, chronic nature. The framework properly treats these considerations in detail, separately.

If the nonnuclear risk estimates are not found to be overstated, then the risk levels suggested by the trial criteria lie in a range of implicitly accepted risks. The lower end of the range indicated for the nuclear plant appears to be not only in compliance with the trial upper limit but also reasonable, in some sense, when compared to the goal level. However, no confidence levels are stated; if, for a particular nuclear facility, for example, the probabilities of the underlying accident sequences are in error by a factor of 100, then this qualitative assessment would change.

3.2.3 Limits on Societal Risk

Limits are placed on the measure of societal risk to ensure that the social cost of a technology has an upper bound. Such limits are typically advanced after first reflecting upon the societal benefit derived from a particular technology and the societal cost of alternative (existing or proposed) technologies available to achieve that same benefit.

The determination of societal risk and its use as an index of the social cost of a technology, while informative, is more complex than the case of individual risk. The frequency of undesirable events as well as the magnitude of the ensuing consequence are difficult to determine with small uncertainty. Thus a single number, such as the calculated expected value of the social cost, cannot be expected to reflect a detailed description of the societal risk, or how its measure is determined. In addition, the measure of societal risk can be based on different consequences: early and latent deaths, area of land contaminated, property damage, etc. While societal risk acceptance criteria might include other potential consequences, the trial criterion in Table 3.1.1 is based on the number of deaths per year.

The range of point estimates of the societal risk for the case studies treated in Appendices A, B and C are indicated in Table 3.2.2.

Within the limits of this investigation, the trial criterion appears to be comparable to or less than existing societal risks assessed at the expected value. The societal risk of the hypothetical nuclear power plants, as assessed, meet this criterion. This conclusion would be true even if the estimated nuclear plant risks in the RSS were low by a factor of 100.

Additional difficulties exist in making comparisons of expected values to a single criterion. The expected values from the coal analyses, for

TABLE 3.2.2* RANGE OF POINT ESTIMATES FOR SOCIETAL RISK

Technological Endeavor	Calculated Expected Value of the Societal Risk in Deaths per year
Hypothetical nuclear power plant	2×10^{-2} - 5×10^{-2} (latent deaths from large accident)
Hypothetical coal-fired power plant	10 - 50 (latent deaths from normal operation)**
Canvey Island industrial complex	7 - 11 (early deaths from large accident)
Limit on the expected value of societal burden as specified in Table 3.1.1	10 deaths per site year

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* The indicated ranges are only meant to represent published values and are not meant to be comprehensive. An array of technological safety measures are represented (e.g., the hypothetical coal plants, in this table, have no controls for the removal of sulfur from their airborne effluents.) The indicated ranges do not represent uncertainty bounds, but a range of point estimates.

The hypothetical nuclear plants are the RSS reactor, and the RSS PWR scaled in size to 2895 MWt and placed on the Indian Point and Zion sites [2]. These risk estimates, as assessed, are dominated by delayed effects. The indicated range is based on point estimates of the risk of the three hypothetical nuclear power plants; the factor of 100, employed earlier to reflect an unspecified degree of uncertainty, was not incorporated in these estimates.

** Values up to 200 latent deaths per plant year have been estimated by Hamilton and Manne in their review in IAEA Bulletin, Vol. 20, No. 4, p. 44 (1980).

example, reflect chronic effects averaged over a health impact distribution, constructed to reflect uncertainty [3], whereas the expected value from the Canvey Island study is a time average over low frequency-high consequence events.

This framework possesses additional mechanisms to address societal risk: a risk aversion model, and a criterion that would require cost-effective improvements once other societal risk criteria are met. Implications arising from the use of such mechanisms are discussed in the next two Sections of this report.

3.3 Risk Aversion

3.3.1 Introduction

If a society views a single large accident as being more significant than many small accidents which have the same total consequence, then that society is said to be risk averse. The term "risk aversion" is used in the present work primarily to refer to the mechanism incorporated into the risk acceptance framework which reflects this societal behavior. A possible mechanism is provided that would enable risks of differing nature to be more easily interrelated. The framework proposed in Part 2 [1] advocates the use of risk aversion in the consideration of early deaths only. In the present work, risk aversion is applied to both early and delayed deaths for illustrative purposes.

3.3.2 A Simple Model for Risk Aversion

The product of the frequency of an event and its consequence is commonly taken as a measure of risk. A simple model [6] to provide a mechanism for expressing risk aversion inflates the consequence by assuming that the societal cost of an accident resulting in N fatalities is N^{α}. For $\alpha = 1$ the simple measure of the expected value of the consequence is recovered. For values of α greater than one, accidents with large consequences can be weighted to reflect society's aversion. The trial framework, for example, proposes that a value of 1.2 be used for α as a starting point. The use of risk aversion may magnify the social costs of a technology, for it is the resulting number of <u>equivalent</u> deaths per year that is to be compared to the criteria. To illustrate the effect of this simple risk aversion model, the equivalent social cost of two accidents with consequences of 10 and 1000 deaths, respectively, are tabulated for a range of values of α in Table 3.3.1.

Thus, careful consideration must be used to ensure a proper choice of α. For example, if $\alpha = 3$ were chosen, then an accident involving a thousand deaths would be equated to the sum of individual accidents involving a large fraction of the entire world's population.

It is clear that this simple model of risk aversion itself introduces uncertainty in the analysis. However, while it is recognized that α clearly cannot be a constant across the entire range of consequences, this model, for appropriate values of α, is a convenient vehicle for attempting to represent societal attitudes.

3.3.3 Application to Case Studies

To emphasize the effect of applying the power-law model of risk aversion to the technological endeavors considered, representative multiplicative factors by which the expected value of the number of deaths is increased are indicated in Table 3.3.2.

The dependence of the effective social consequence on the exponent is graphically indicated in Figure 3.1.

If the trial value of $\alpha = 1.2$ is used, the assessed effective number of deaths per year are shown in Table 3.3.3.

TABLE 3.3.1 INFLUENCE OF NUMERICAL VALUE OF α ON NUMBER OF EQUIVALENT DETAILS

	Actual Number of Deaths	Equivalent Number of Deaths			
Accident	(α = 1)	α = 1.2	α = 1.5	α = 2	α = 3
#1	10	16	32	100	1000
#2	1000	3980	31,600	1 million	1 billion

Table 3.3.2*

Technological Endeavor	Factor by which Expected Number of Deaths Would be Increased			
	$\alpha = 1$	$\alpha = 1.2$	$\alpha = 1.5$	$\alpha = 2$
Hypothetical nuclear power plant	1	4-6	40-80	2600-8300
Canvey Island industrial complex	1	5-6	65-75	4500-6000

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* Factors were estimated for the RSS reactor, and the RSS PWR scaled in size to 2895 MWt and placed on the Indian Point site[2]. These are multiplicative factors shown to illustrate effects of the simple risk aversion model and are <u>not</u> estimates of the risk.

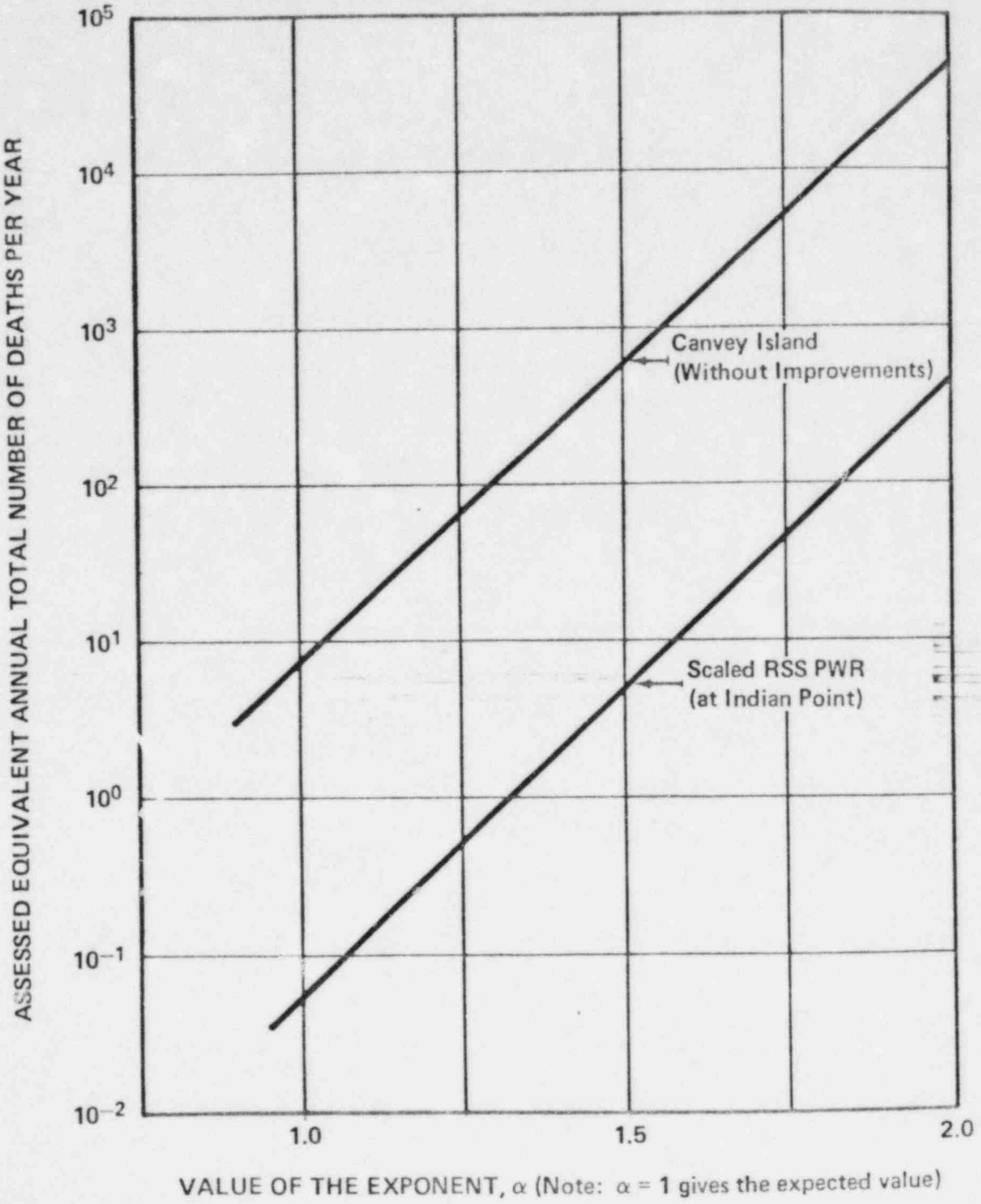

Figure 3.1 Effect of the Numerical Simple Risk Aversion Model When Applied to a Hypothetical Nuclear Power Plant and the Canvey Island Industrial Complex.

TABLE 3.3.3* RANGE OF POINT ESTIMATES OF SOCIETAL RISK USING POWER-LAW RISK AVERSION MODEL (α=1.2)

Technological Endeavor	Effective (Equivalent) Number of Deaths per year
hypothetical nuclear power plant	0.1 - 0.4 (effective delayed deaths from large accident)
Canvey Island industrial complex	35 - 66 (effective early deaths from large accident)
Limit on the expected value of societal burden as specified in Table 3.1.1	10 deaths per site year

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* The indicated ranges do not represent uncertainty bounds, but a range of point estimates. The hypothetical nuclear plants are the RSS reactor and the RSS PWR placed on the Indian Point and Zion sites and scaled in size to 2895 and 3150 MWt, respectively [2]. These risk estimates, as assessed, are dominated by delayed effects.

Thus, the Canvey Island complex (without improvements), which is marginal in relation to the societal risk criterion at $\alpha = 1$, would not meet that criterion for $\alpha = 1.2$. The hypothetical coal-fired power plants discussed in Appendix B are not included in the above lists; society does not seem to be risk-averse to the impacts from coal since such impacts, to date, are of a steady state nature and result from what are considered to be normal operations. Note that if such deaths were treated as resulting from a common event and not as separate individual deaths, then risk aversion modeling would quickly multiply the 10 to 50 deaths per year into rather large numbers of equivalent deaths.

3.4 Cost-Effective Risk Reduction

3.4.1 Introduction

As Low As Reasonably Achievable (ALARA) concepts are employed to ensure that cost-effective technological improvements will be made beyond those dictated by societal risk criteria. Attempts to specify an ALARA principle have chiefly focused on economic arguments; the current state of knowledge, however, allows a large variance to exist in such quantifications [7]. The approach taken in the framework proposed in Part 2 [1] may help to alleviate these difficulties by recommending two distinct cost values for early and latent effects, respectively. The justification of the division is that society places different values on the impact of early versus delayed deaths. In addition, the framework proposed in Part 2 [1] includes the consideration of economic losses, which is beyond the scope of the present work.

3.4.2 Application to Case Studies

Specific attention must be paid in formulating the details of any risk management concept to ensure that such a mechanism is effective in controlling as well as characterizing risk within the overall framework. In the case of a cost-effective risk reduction criterion, the relevant considerations would include not only proper limits on the expenditure per death averted, but also the confidence level at which the criterion is to be applied and the methods employed to treat uncertainty and risk aversion. The implications of these considerations are examined through the application of a cost-effective risk reduction requirement to the hypothetical coal-fired and nuclear power plants. More extensive considerations are presented in Appendices A, B. and C.

The hypothetical coal-fired power plant with the lowest societal burden (see Appendix B) has an expected societal burden of 10 deaths per year (with no sulfur control). While this expected value, as assessed, marginally satisfies the societal risk criterion from Table 3.1.1, cost-effective improvements would be required. For example, as shown in Appendix B, eliminating 50% of the sulfur emissions would cost $10 million per year, avert 5 deaths per year, and therefore satisfy a $2 million per death averted requirement. For a $1 million per death averted requirement, such a sulfur removal system would not be cost-effective.

The 90% upper confidence bound of the societal burden of this same uncontrolled coal-fired plant is 27 deaths per year*, as discussed in Appendix B. If the trial criteria were to be applied at this high level of confidence, the hypothetical uncontrolled plant would not meet the societal risk criterion. However, it is of some value to consider the implications of applying cost-effective criteria at this level of confidence, even though such an application is not specifically advocated by the framework of Part 2 [1]. A $2 million per death averted cost-effectiveness requirement would mandate the removal of 96% of the sulfur; 26 deaths per year would be averted at an annual cost of $52 million. A $1 million per death averted requirement would mandate an

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* There is a 90% chance (or probability) that the number of deaths per year is 27 or less. In this particular case, the calculated expected value is 10 deaths per year.

annual expenditure of \$20 million with 75% sulfur removal and averting 20 deaths per year. Thus, depending on how an ALARA concept were to be applied, the cumulative cost over a 30-year plant life could range from \$0 to \$1.56 billion.

In Appendix A, the risks due to two hypothetical nuclear power plants[*] are compared to that of the RSS reference reactor. As indicated in that Appendix, each of these plants, as assessed, meets the societal risk criterion for values of the risk aversion exponent, α, less than 1.5. However, if the assessed risk of the RSS reactor is used as a goal for the other units, expenditures up to \$1.0 million and \$1.7 million (total) would be cost-effective (\$2 million per death averted requirement). If risk aversion[**] were introduced, these upper limit expenditures now jump to \$70 million and \$190 million for $\alpha = 1.5$, and to tens of billions of dollars for $\alpha = 2$, clearly a prohibitive sum.

The treatment of uncertainty can be introduced at this point. If the nuclear risk estimates are in error, in a nonconservative manner, by a factor of ten, a range of total cost-effective expenditures of up to \$9 million and \$17 million is calculated for a \$2 million per death averted cost-effectiveness criterion. A factor of 100 uncertainty could increase the magnitude of the total cost-effective expenditures to \$90 million and \$170 million.

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[*] The RSS PWR placed on the Indian Point and Zion sites and scaled in power to 2895 MWt and 3150 MWt, respectively [2].

[**] This application of risk aversion would be separate from that discussed in Section 3.3, and is not part of the trial criteria.

Regardless of the accuracy of the power plant models employed (both nuclear and coal-fired), a variety of interpretations of an ALARA requirement indicates that such a requirement must be clearly formulated, with detailed attention paid to the resulting implications, so that it can be used as an effective hazard management technique. In addition, an economic component should be included for a complete determination of cost-effectiveness.

3.5 Discussion and Conclusions

3.5.1 Discussion

Part 3 of this report has considered the application of simplified trial criteria to three technologies: hypothetical nuclear and coal-fired power plants, and the Canvey Island industrial complex in England. It appears that the criteria, if they are to be met, would require improvement of the safety of some existing, accepted technological endeavors. The question of whether such an application of criteria developed for nuclear-related decision making is appropriate for other technologies, has not been considered. However, the broad application of criteria should help in the continuing evolution of regulatory policy by providing insight into the science of risk, the implications of various policy options, as well as the acceptability and public perception of risk.

3.5.2 Conclusions

As a result of this study, the following can be concluded:

1. The trial criteria for individual risk (from Table 3.1.1) are more stringent than the assessed individual risks due to the existing nonnuclear technological facilities considered. The lower end of the assessed nuclear related individual risks lies below the range specified by the criteria.

2. The trial criterion of 10 equivalent deaths per year as a measure of societal risk (from Table 3.2.2) appears to be reasonably representative of the lower end of risks

which has been estimated for coal-burning plants. If nuclear power is to be an option in the U.S., its risks should not be greater than those for accepted nonnuclear power sources. The societal risk for a hypothetical nuclear plant, as assessed in Appendix A meets this criterion even if its assessment in WASH 1400 is in error by a factor of as much as 100.

3. Care must be taken when quantifying the cost-effective risk reduction and risk aversion criteria. While they are appropriate considerations, which are presently modeled in a simplistic manner, they can rapidly become the limiting factors in considering the acceptance of the risk. If the trial cost-effective value is applied to the nonnuclear technologies, the total amount spent on required improvements can become quite high (on the order of the capital cost of the plant) and still be labelled "cost-effective." If economic effects are also included in the cost-effective criterion, expenditures will be even larger.

4. One area left unspecified in the framework is the question of what constitutes a proper risk analysis. This would include the establishment of an accepted methodology which would properly treat uncertainties as well as define the scope of the analysis. The resolution of this concern, which is beyond the scope of the present effort, is at least as

formidable a task as the development of the risk acceptance framework itself.

5. The proposed framework appears to be of a form that addresses some of the relevant concerns by providing diverse mechanisms to manage risk. The trial criteria of Part 2 [1] have additional flexibility, and would make a reasonable starting point for the development of a set of quantitative risk criteria.

3.6. References

1. J.M. Griesmeyer and D. Okrent, "Risk Management and Decision Rules for Light Water Reactors," Part 2 of this report.

2. J.L. Sprung, "An Investigation of the Adequacy of the Composite Population Distributions Used in the Reactor Safety Study," SAND 78-0556, 1978.

3. M.G. Morgan, D.C. Morris, A.K. Meier, and D.L. Shenk, "A Probablistic Methodology for Estimating Air Pollution Health Effects from Coal-Fired Power Plants," Energy Systems and Policy, vol. 2, pp. 287-310, 1978.

4. E.P. O'Donnell and J.J. Mauro, "A Cost-Benefit Comparison of Nuclear and Nonnuclear Health and Safety Protective Measures and Regulations," Nuclear Safety, vol. 20, pp. 525-540, 1979.

5. Health and Safety Executive (UK), "Canvey: An Investigation of Potential Hazards from Operations in the Canvey Island/Thurrock Area," London: Her Majesty's Stationary Office, 1978.

6. J.M. Griesmeyer, M. Simpson, and D. Okrent, "The Use of Risk Aversion in Risk Acceptance Criteria?," UCLA-ENG-7870, October, 1979.

7. K.A. Hsieh, "Evaluation of the Economic Risk from Nuclear Power," MS Thesis Oregon State University, OSU-NF-7708, 1978.

APPENDIX A

Application of Risk Acceptance Criteria to Nuclear Power Plants

A.1 Introduction

Both societal and individual risks were estimated for two reactors* in the Reactor Safety Study (RSS) [A.1]. Individual risks were expressed in terms of the probability of early and delayed fatality; societal risks were expressed in terms of total early and delayed fatalities, area of land contamination and property damage among others. While the RSS considered only "dominant" accident scenarios and neglected certain external events, it provides a convenient and valuable source with which to illustrate the use of risk acceptance criteria.

This appendix first examines the question of individual risk and compares the estimated risk with the trial criteria of Table 3.1.1. Societal risk estimates are taken from the RSS or RSS follow-on studies. The implications of the application of risk aversion and the ALARA principle are also investigated.

The RSS and similar studies express societal risks via complementary cumulative distribution functions (i.e., graphical representations that convey the probability or frequency of the consequences exceeding a value, X, as a function of X). Such functions from the RSS

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* A Boiling Water Reactor (BWR) represented by Peach Bottom and a Pressurized Water Reactor (PWR) represented by Surry, but each assumed to be located on a composite site.

describing early fatalities and total delayed cancers for a composite site are depicted in Figures A.1 and A.2, respectively.*

Figures A.3 and A.4 [A.2] describe selected effects of placing the RSS PWR, scaled appropriately for size, on selected sites. The referenced study was originally meant to investigate the adequacy of the composite site model of the RSS; however, in the present work, for convenience, the work by Sprung [A.2] is taken to represent the "safety profile" of several hypothetical reactors and is used in the spirit of illustration.

A.2 Individual Risk

The risk** to which an individual located near a nuclear power plant is exposed is considered in this section. The calculations presented here are not strictly for the Maximum Exposed Individual. For most cases, however, they are appropriate for individuals near the plant.

A.2.1 Individual Risk of Acute Death

In this example, the model of the PWR described in the Reactor Safety Study, scaled to 2895 MWt, was utilized to estimate the risk to an individual near the site. Two cases were considered: Case I, an

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* Figure A.2 represents the total latent death divided by the 30 year period following the accident to yield a measure of the consequence "per year". These values should be multiplied by a factor of 30 to yield a measure of the total consequence.

** Based on accidential releases of radioactive materials; steady state releases also contribute to individual risk.

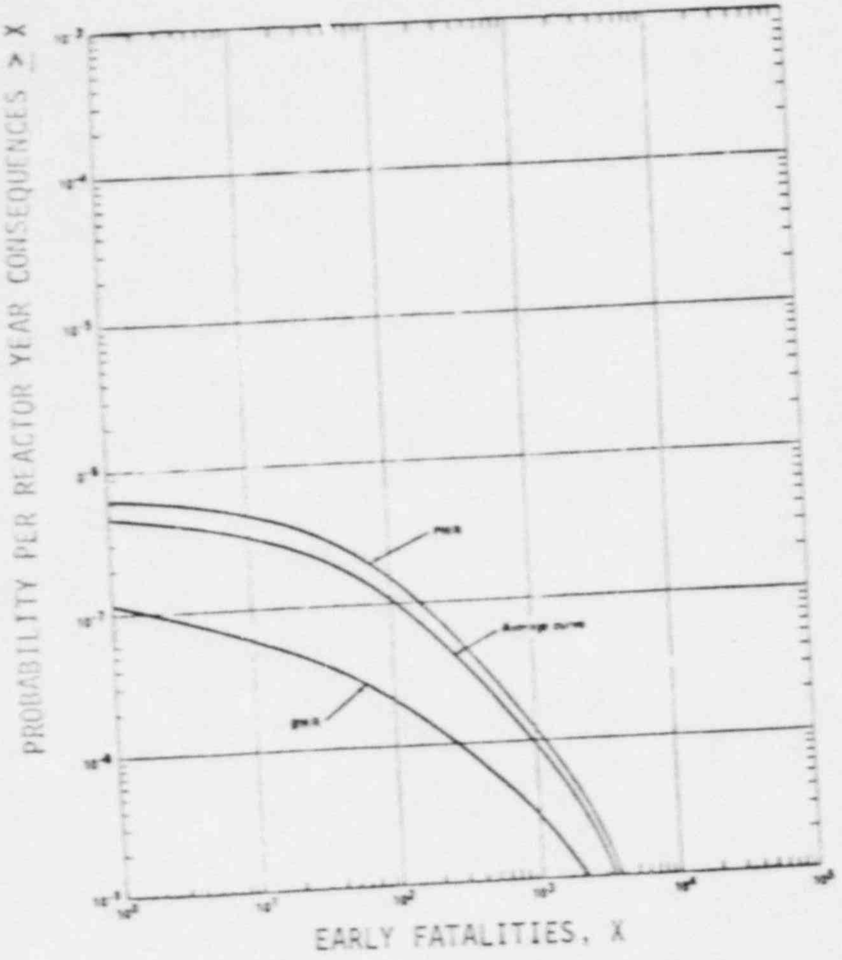


FIGURE A.1
PROBABILITY DISTRIBUTION (CCDF) FOR EARLY FATALITIES PER REACTOR YEAR

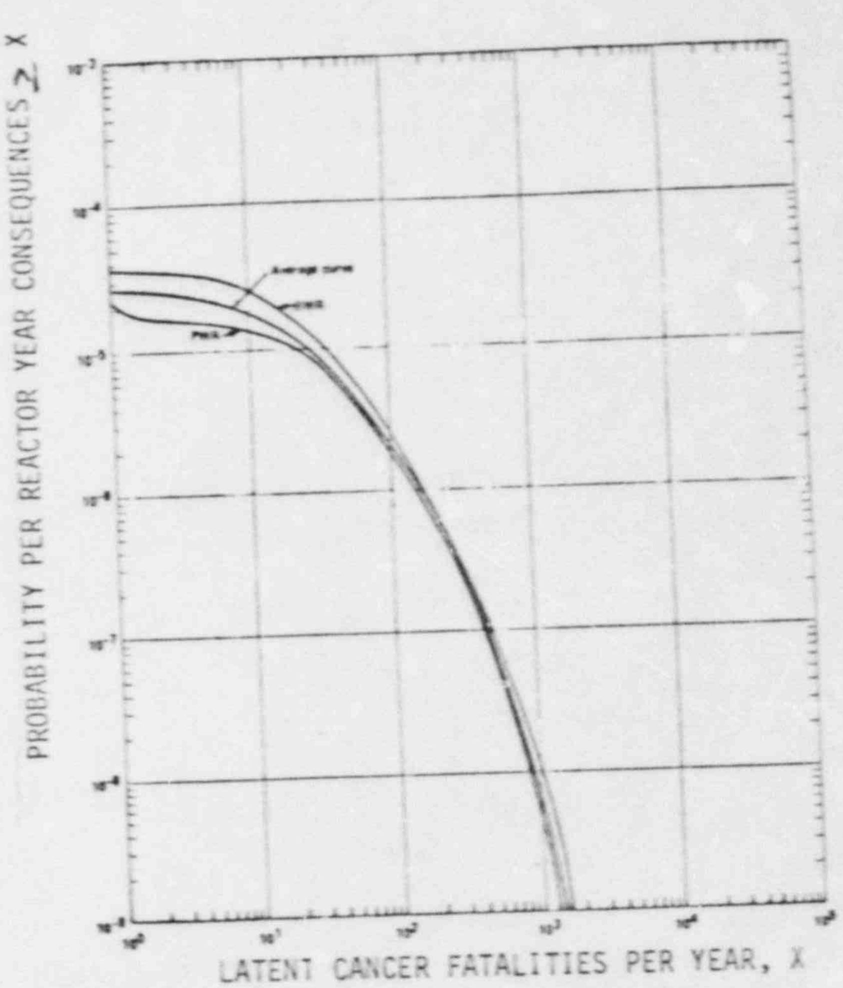


FIGURE A.2
PROBABILITY DISTRIBUTION (CCDF) FOR LATENT CANCER FATALITY INCIDENCE PER REACTOR YEAR DIVIDED BY 30 (TOTAL LATENT CANCER FATALITIES CAN BE FOUND BY MULTIPLYING X BY 30).

FROM REFERENCE (A.1)

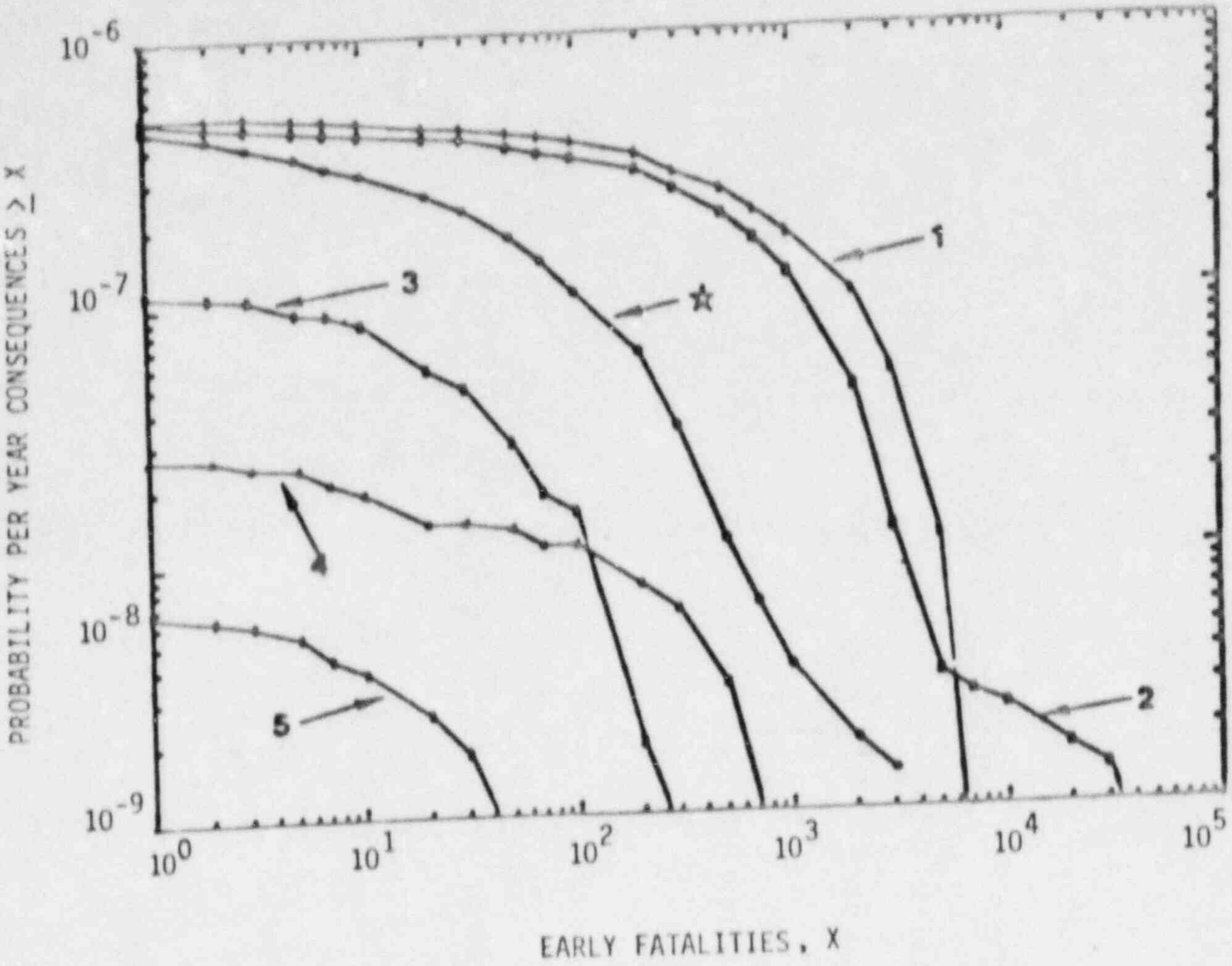
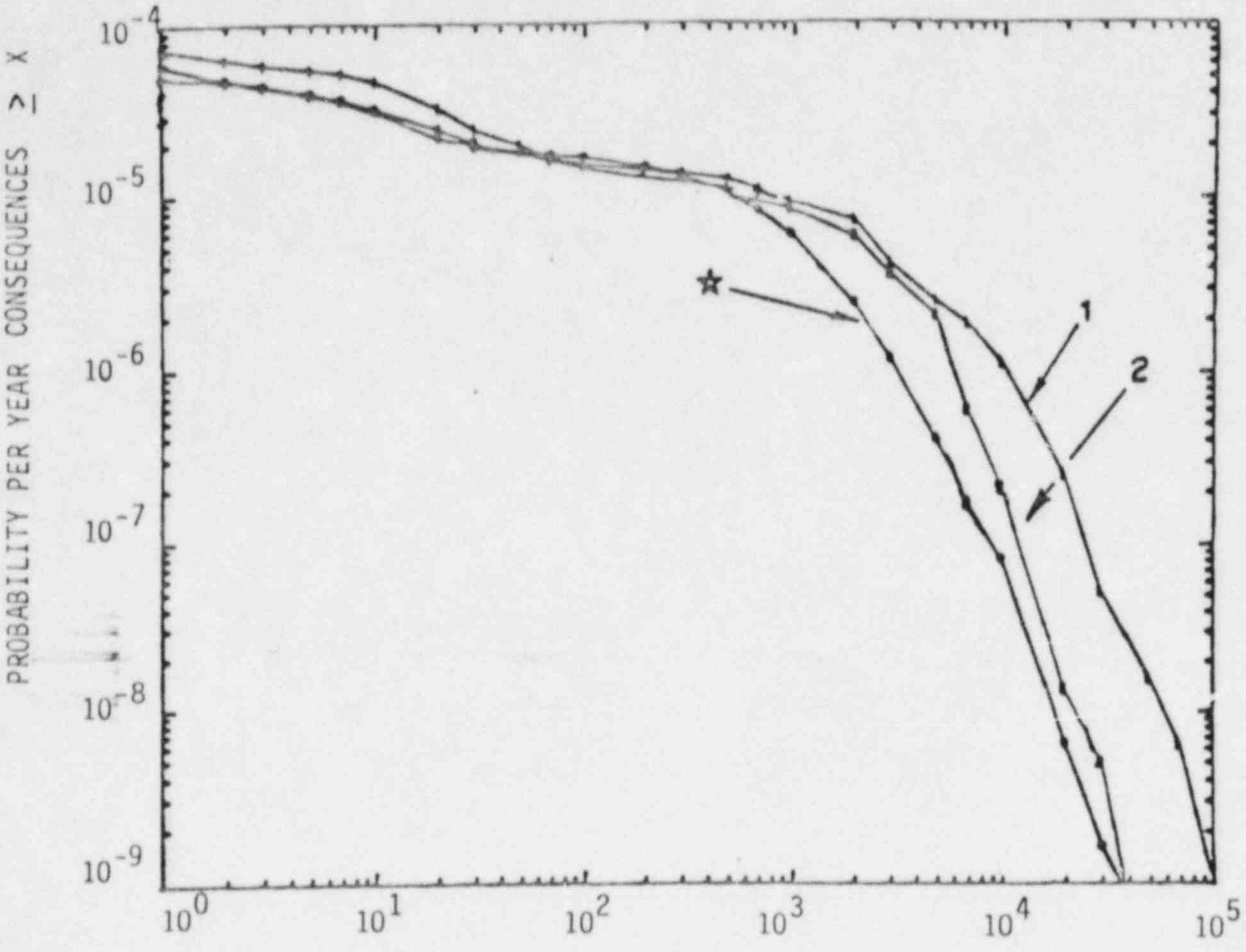


FIGURE A.3 **Log-Log plot of probability (per reactor-year) versus early fatalities showing the dispersion of site specific CCDF's about the Reactor Safety Study CCDF.**

*RSS (consequences derived from the aggregate effects of 100 reactors (A.1) divided by 100)

1. RSS PWR at Indian Point scaled to 2895 MWt
2. RSS PWR at Zion scaled to 3150 MWt
3. RSS PWR at Palo Verde scaled to 3713 MWt
4. RSS BWR at Millstone scaled to 1956 MWt
5. RSS PWR at San Onofre scaled to 1290 MWt

FROM REFERENCE (A.2)



TOTAL DELAYED CANCER FATALITIES, X

FIGURE A.4 PROBABILITY DISTRIBUTION (CCDF) FOR DELAYED CANCER FATALITIES PER YEAR FOR SPECIFIC HYPOTHETICAL SITES

* RSS (consequences derived from the aggregate effects of 100 reactors (A.1) divided by 100)

1 RSS PWR AT THE INDIAN POINT SITE scaled to 2895 MWt

2 RSS PWR AT THE ZION scaled to 3150 MWt

FROM REFERENCE (A.2)

individual located initially within 0.5 to 1 mile of the reactor; and, Case II, an individual initially located 1 to 1.5 miles from the reactor. In both cases, a simplistic evacuation model was employed. As is evident, this is not a calculation for the maximum exposed individual. The individual risk was calculated by summing the products of the probability that an individual would receive a dose greater than 200 rem, given a particular accident sequence, and the frequency of that accident sequence.* As shown in Tables A.1 and A.2, the two cases yield individual risks of 3.5×10^{-7} per year and 3.0×10^{-7} per year, respectively.

The evacuation model** employed in the above analysis may tend to underestimate the risk. One estimate [A.3] of the reduction of risk by an effective evacuation (1.2 mph) relative to no evacuation for one particular release category is a factor of 3 for individuals within 2.5 miles of the plant.

In addition to uncertainties arising from evacuation and dose-response modeling, the above estimates consider only a predefined set of accident scenarios. If the frequencies of these scenarios, taken from

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* The calculations reflected in Tables A.1 and A.2 assume 100% mortality for individuals receiving a dose greater than the assumed threshold value for non-stochastic effects. This approach is conservative; however, the calculations indicate, that for the small distances considered, the risk would roughly decrease only by a factor of 2 if a threshold of 700 rem is assumed.

** One-hundred percent of the population within 5 miles of the plant immediately proceed radially away from the site at 1.1 mph.

TABLE A.1

Case I: Risk of Immediate Death to Individual Originally Located 0.5 to 1 Mile from RSS PWR Scaled to 2895 MWt.

Release Category*	Probability (P_i) Dose $\geq$ 200 Rem	Frequency (F_i) of Release (yr^{-1})*	P_iF_i
1A	0.028	4×10^{-7}	1.1×10^{-8}
1B	0.018	5×10^{-7}	9.0×10^{-9}
2	0.022	8×10^{-6}	1.7×10^{-7}
3	0.029	4×10^{-6}	1.2×10^{-7}
4	0.031	5×10^{-7}	1.6×10^{-8}
5	0.028	7×10^{-7}	2.0×10^{-8}
6	0	6×10^{-6}	0
7	0	4×10^{-5}	0
8	0	4×10^{-5}	0
9	0	4×10^{-4}	0

$$R = \sum_i P_iF_i = 3.5 \times 10^{-7} \ yr^{-1}$$

* from RSS [A.1]

TABLE A.2

Case II: Risk of Immediate Death to Individual Originally Located 1 to 1.5 Mile from RSS PWR Scaled to 2895 MWt.

Release Category*	Probability (P_i) Dose $\geq$ 200 Rem	Frequency (F_i) of Release (yr^{-1})*	P_iF_i
1A	0.029	4×10^{-7}	1.1×10^{-8}
1B	0.013	5×10^{-7}	6.7×10^{-9}
2	0.015	8×10^{-6}	1.2×10^{-7}
3	0.032	4×10^{-6}	1.3×10^{-7}
4	0.029	5×10^{-7}	1.4×10^{-8}
5	0.026	7×10^{-7}	1.8×10^{-8}
6	0	6×10^{-6}	0
7	0	4×10^{-5}	0
8	0	4×10^{-5}	0
9	0	4×10^{-4}	0

$$R = \sum_i P_iF_i = 3.0\times10^{-7}\ yr^{-1}$$

* from RSS [A.1]

the RSS [A.1] were low by a factor of 100 and with no other sources of uncertainty, then the risk of early death for an individual living near the reactor would be on the order of $3x10^{-5}$ per year.

When compared to the trial upper limit criterion of $5x10^{-6}$ per year, the latter risk violates the criterion. A more detailed, careful analysis is needed. Note that in the original analysis, if the effects of uncertainties and omissions were small, then the goal level of the criterion from Table 1.1 would be satisfied.

A.2.2 Individual Risk of Delayed Death

The probability of an individual developing a fatal cancer due to the operation of a nuclear power plant should be evaluated for both the case of normal operation and for a range of accident scenarios. The former contribution can be estimated via actuarial effluent release data. The latter contribution can be approximated using the methodology utilized in the Reactor Safety Study.

In 1976 Miettinen, et al, [A.4] estimated the whole body gamma dose to an individual located 1500 meters from a nuclear power plant based on measured airborne effluents from U.S. Light Water Reactors (LWRs). Waterborne effuents and ingestion pathways were not taken into account. Miettinen used a log-normal distribution to describe the statistical distribution of the annual effluent releases during 1972-1974 and tabulated the mean values and the 95% upper bounds for both BWRs and PWRs.

The mean release was estimated to result in a dose to the reference individual of ~2 mrem and 0.01 mrem for BWRs and PWRs, respectively. Extrapolation to the 95% upper bound, as tabulated by Miettinen, would result in doses to the reference individual of approximately 10 mrem and 0.3 mrem, respectively.

Using the standard ICRP relationship of approximately 10^{-4} fatal cancers/rem, the 95% upper bound of the distribution describing the releases from a BWR would imply an upper bound* on the annual risk of fatal cancer of about 10^{-6}. It must be noted that this value may not be indicative of modern BWRs; since 1974, off-gas recombiners and additional effluent holdup capacity has tended to reduce off site releases (e.g., during the first half of 1979, the three unit Browns Ferry site reported releases roughly a factor of 100 lower than those tabulated by Miettinen for isotopes of krypton and iodine [A.5]). The effect of excluding water and ingestion pathways was not evaluated.

For accidental releases, RSS methodology and results can be used to approximate individual risk. Figure A.5 shows the general dependence of the risk of delayed death to an individual as a function of distance from the RSS PWR on a hypothetical site. Since values of the ordinate in this figure are conditional on a set of predefined release categories, more detailed information is needed to quantify the risk.

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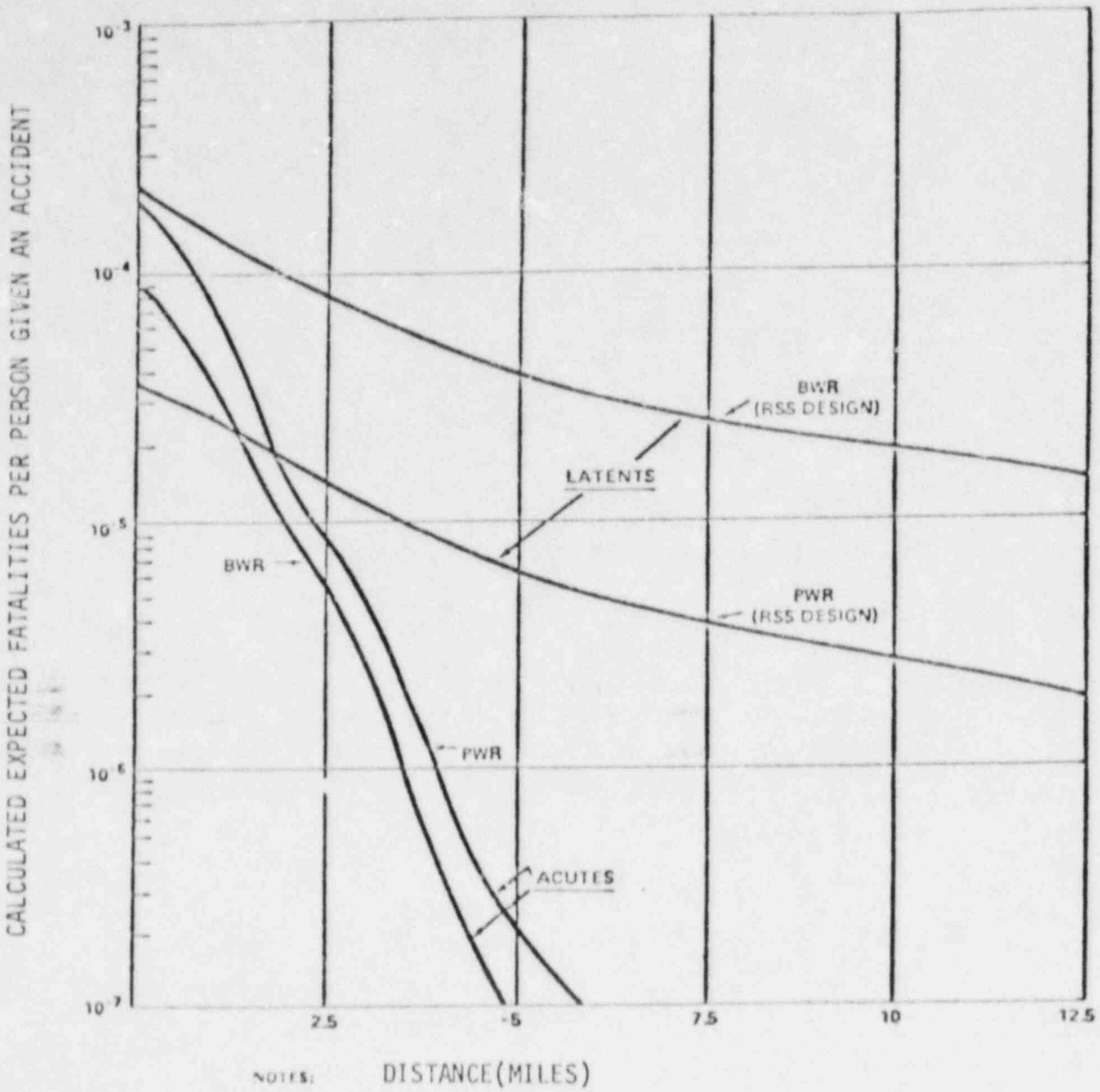
* That is to say, there is a high level of confidence that the risk of delayed death is about 10^{-6} per year, or less, for the pathway considered, due to a pre-1974 BWR. If evaluated for the mean release, this same unimproved average BWR would have a risk contribution of about $2x10^{-7}$ per year.



NOTES:

1. LATENT FATALITIES FROM IMMEDIATE UPTAKES FROM ACCIDENTS, NO CHRONIC EFFECTS ARE INCLUDED FROM LONG TERM SHINE OR LONG TERM PATHWAYS.

2. CURVES ALSO INCLUDE NON-COREMELT ACCIDENTS DESCRIBED IN THE RSS.

FIGURE A.5 Calculated risk to an individual of acute death and latent death versus distance following reactor accidents described in the RSS

FROM THE NRC STAFF

This type of information is depicted in Figure A.6. Combining the probabilities of the release sequences shown on Figure A.6 with the corresponding conditional risk, one can, for example, make a point estimate of the risk of fatal cancer at 5 miles as approximately 2×10^{-9} per year.

The above point estimates for the risk of fatal cancer induction are well below the corresponding goal level of the trial criterion. However, uncertainties and omissions have not been adequately addressed. For these reasons, the above values may not be good measures of the actual risk.

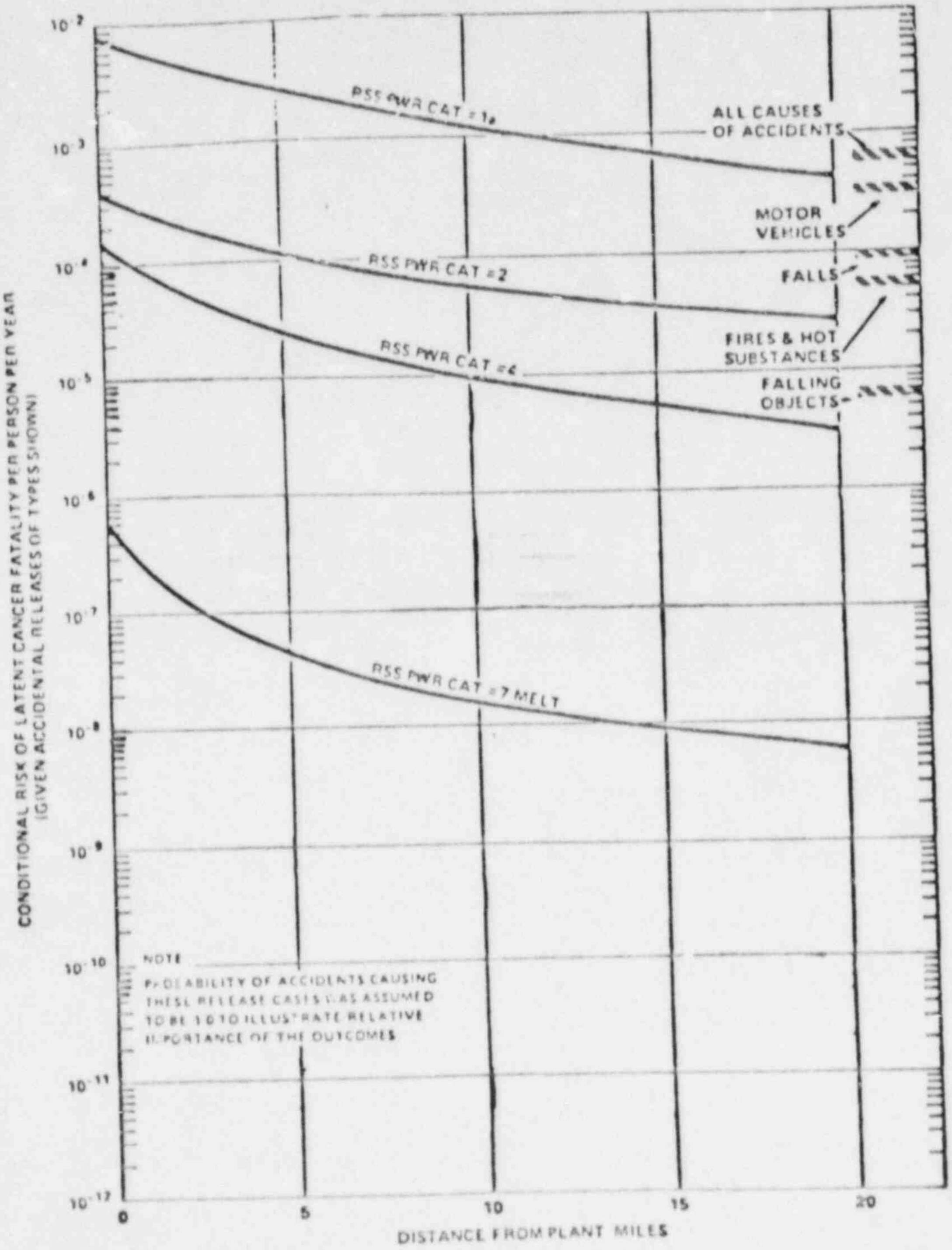
A.3 Expected Value of the Societal Risk

The complementary cumulative distribution functions (CCDFs) given in Figures A.1-A.4 can be used to estimate the expected value of the societal risk. Given a consequence (e.g., early death), the risk is expressed as consequences per year. Note again that in Figure A.2 the number of latent cancer fatalities is given in units of consequences per year and is somewhat misleading. Figure A.2 represents the total latent deaths divided by the 30 year period following the accident. These values should be multiplied by a factor of 30 to yield measures of the total latent cancer incidence.

The curves in Figures A.3 and A.4 are for the RSS PWR reactor placed on five actual sites and scaled by power rating to the reactors on those sites. The expected values are shown in Table A.3.

FIGURE A.6

INDIVIDUAL RISK OF FATALITY FROM VARIOUS ACCIDENT CAUSES/YEAR



NOTE

PROBABILITY OF ACCIDENTS CAUSING THESE RELEASE CASES WAS ASSUMED TO BE 1.0 TO ILLUSTRATE RELATIVE IMPORTANCE OF THE OUTCOMES

FROM THE NRC STAFF

TABLE A.3

CALCULATED EXPECTED VALUE OF THE RISK FOR THE SURRY REACTOR PLACED ON SELECTED SITES AND SCALED TO THE POWER OF THE REACTOR AT THAT SITE.

REACTOR SITE	RISK (deaths/reactor year)*	
	EARLY	LATENT (total)
RSS (WASH-1400)**	4.4×10^{-5}	2.7×10^{-2}
RSS (Updated)**	4.0×10^{-5}	2.1×10^{-2}
RSS PWR at Indian Point scaled to 2895 MWt	4.7×10^{-4}	5.0×10^{-2}
RSS PWR at Zion scaled to 3150 MWt	2.5×10^{-4}	3.5×10^{-2}
RSS PWR at Palo Verde scaled to 3713 MWt	4.3×10^{-6}	not available
RSS BWR at Millstone scaled to 1956 MWt	3.0×10^{-6}	not available
RSS PWR at San Onofre scaled to 1290 MWt	4.9×10^{-8}	not available

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* All but RSS [A.1] are derived from the work of Sprung [A.2]. The consequences of the RSS reactor is approximated from the aggregate consequences of the 100 reactor population [A.1] divided by 100.

** The difference in values for these two cases is attributed to updating the consequence modeling in the computer codes used to generate the curves. The updated values were used in plotting the curves in Figure A.5.

It must be emphasized that these values do not represent the risks at these sites because the fault and event trees used to generate the frequencies are those for the RSS reactor which may be very different from the reactor on the sites listed. Furthermore, uncertainties have not been addressed and the analyses are of limited scope. Hence, the quoted values are to be considered applicable to hypothetical reactors only.

Examination of Table A.3 shows the following:

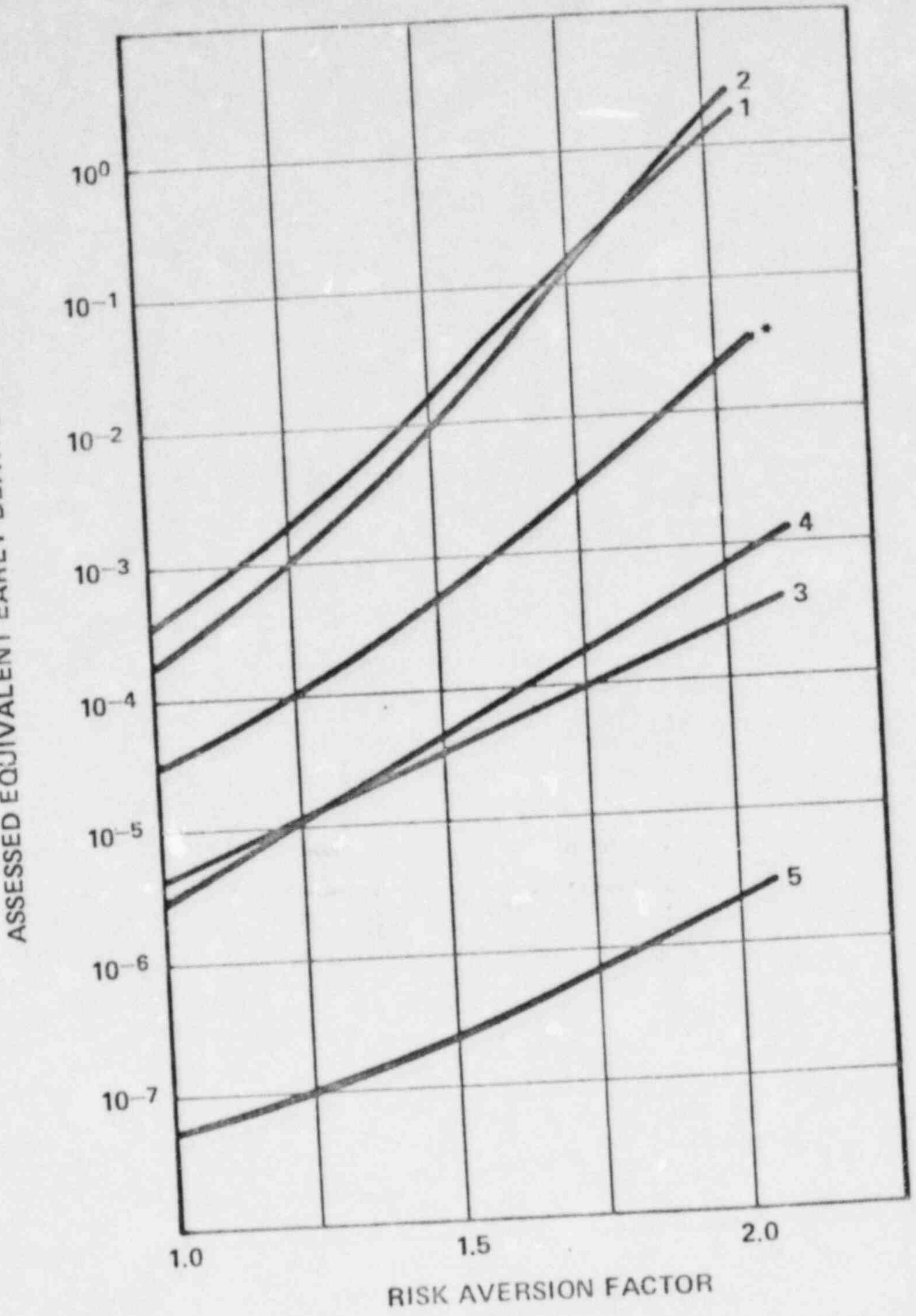
a) the total delayed effects dominates the early effects as a contribution to risk for each case where a calculation has been made, and

b) the risk of early death appears to be much more sensitive to the site than latent deaths.

A.3.1 Risk Aversion and Risk Acceptance

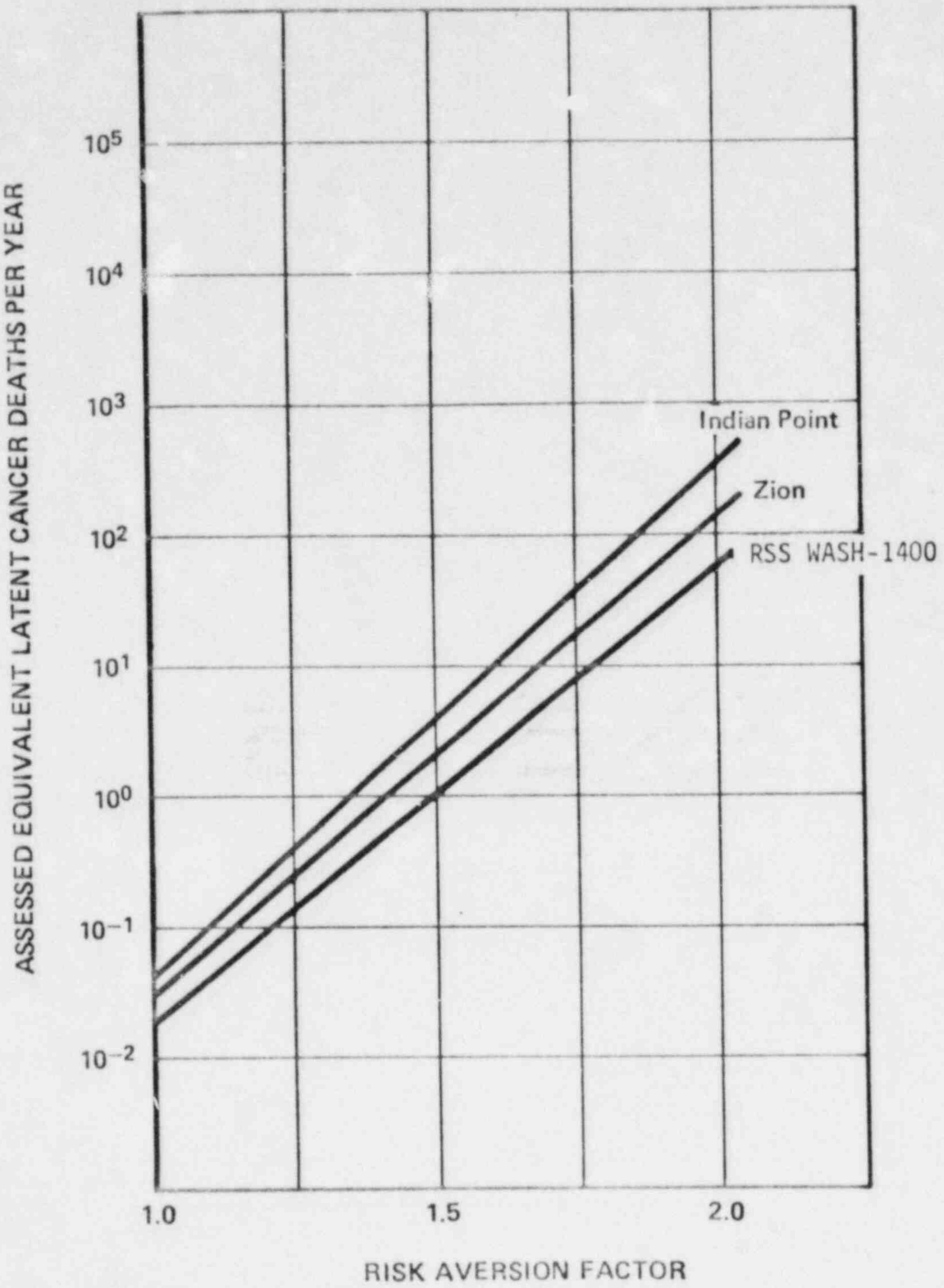
To account for the apparent public aversion to high consequence events, a simple model suggests that higher moments (i.e., [frequency] x $[\text{consequence}]^{\alpha}$) of the consequence distribution be used as a measure of the expected social cost. The mathematical notation of this expected social cost is $E_c(\alpha)$. When $\alpha = 1$, $E_c(\alpha)$ is just the expected value of the consequence per unit time, or the calculated risk. For $\alpha > 1$, more weight is given to the high consequence events.

In Figures A.7 and A.8, the expected social costs as a function of α are shown for the cases considered in Table A.3. As anticipated, the



- * RSS (consequences derived from the aggregate effects from 100 reactors [A.1] divided by 100)
- 1 RSS PWR at Indian Point scaled to 2895 MWt
- 2 RSS PWR at Zion scaled to 3150 MWt
- 3 RSS PWR at Palo Verde scaled to 3713 MWt
- 4 RSS BWR at Millstone scaled to 1956 MWt
- 5 RSS PWR at San Onofre scaled to 1290 MWt

Figure A.7 Equivalent Social Cost (Assessed Early Deaths/Year) as a Function of the Risk Aversion Factor α.



RSS: Aggregate consequences of 100 reactors [A.1] divided by 100
Indian Point: RSS PWR at Indian Point scaled to 2895 MWt
Zion: RSS PWR at Zion scaled to 3150 MWt

Figure A.8 Equivalent Social Cost (Assessed Total Latent Deaths/Year) as a Function of the Risk Aversion Factor α.

expected social cost increases as α increases. Of interest is the comparison of curves 3 with 4, and 1 with 2, in Figures A.3 and A.7, which depict the number of equivalent early deaths per year for specific sites as a function of α. In each comparison, the curves cross; one has a higher frequency of low consequence events but a lower frequency of high consequence events. For example, with $\alpha = 1$ (no risk aversion), curve 4 represents a lower risk than curve 3, and curve 2 a lower risk than curve 1. With $\alpha = 2$, the relative standing changes, curves 4 and 2 have a higher "effective" cost than their counterparts. As expected, the exponent weights the high consequences events heavily enough to cause this change in their relative standing. The criterion from Table 3.1.1 for societal risk is 10 deaths per year. The risk of early death as depicted in Figure A.7 would meet this criterion for all analyzed cases for values of α less than 2.

Although the parent framework (proposed in Part 2 of this report does not call for risk aversion to be applied to latent deaths, it was applied here for illustrative purposes, as is depicted in Figure A.8. For the risk of fatal cancer, the cases reviewed violate this criterion for values of α greater than approximately 1.5-1.75. Estimates of the effect of uncertainties and component risk omissions on this critical value of α are difficult to make. Such analyses would be part of a rigorous application of criteria, but are beyond the scope of the present work.

A.3.2. Cost-Effective Risk Reduction and Uncertainty

To complement the societal risk limit criteria, an ALARA (As Low As Reasonably Achievable) concept is also used. The ALARA concept can be applied to determine if additional safety features need to be incorporated into existing or planned nuclear power plant by specifying a cost-effectiveness criterion.

The use of the ALARA concept can be illustrated as follows.* Consider the risk of delayed death associated with the plants denoted by curves 1 and 2 of Figure A.4 and the RSS curve, also given in Figure A.4. The corresponding risks of delayed death were:

curve 1	5.0×10^{-2}	deaths per year
curve 2	3.5×10^{-2}	deaths per year
RSS (Updated)	2.1×10^{-2}	deaths per year

Suppose one had developed safety features that reduced the risk from the reactors denoted by curves 1 and 2 so that they had the same risk as the RSS. The number of deaths averted per year would be approximately 3×10^{-2} and 1.4×10^{-2}, respectively. If each of the improvements cost $10 million, the cost per death averted over a 30 year period is $11.5 and $23.1 million, respectively. For a $2 million per death averted criterion, these improvements would not be cost-effective. The maximum cost effective expenditure for these amounts of risk reduction would be $1.7 million and $0.9 million.

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* The parent framework recommends that the ALARA be applied to latent and early deaths separately and includes a factor for economic losses. Only latent deaths are considered here for illustrative purposes.

If society is risk averse, the ALARA concept can be applied at the effective social cost $E_c(\alpha)$. At $\alpha = 1.5$, the effective number of deaths averted per year (for the same example above) becomes 3.1 and 1.2 respectively. Here the cost per equivalent death averted for a \$10 million improvement over a 30 year period becomes \$106,000 and \$271,000 respectively. Using a \$2 million per death averted criterion, one would conclude that improvements should be implemented. In these cases, the maximum cost-effective expenditures become \$190 million and \$70 million. For $\alpha = 2$, the maximum "cost-effective" expenditure runs into the tens of billions of dollars.

Uncertainty can also be introduced into the ALARA concept. As shown above, with no uncertainty and no risk aversion, improving the reactors of curves 1 and 2 at a cost of \$10 million is not warranted. If the assessment of the risk is in error by a factor of +10, the cost per death averted becomes \$1.5 million and \$2.3 million respectively. Hence with a \$2 million per death averted criterion, the improvement is cost-effective in case 1 but not in case 2. If the cost-effectiveness criterion were \$5 million per death averted, both improvements would be required. If the criterion were \$1 million per death averted, neither would be required. Similarly at an uncertainty of +100, both improvements would be required. The maximum cost allowed is \$17 million and \$9 million respectively at +10 uncertainty and \$170 million and \$90 million at +100 uncertainty.

From this analysis it appears that assessed societal risks on the order of 10^{-2} deaths per year are small enough that improvements costing several million dollars are "unreasonable" using a $2 million cost-effectiveness criterion. When risk aversion or uncertainty is introduced, such expenditures can become "reasonable." The analysis appears to be more sensitive to risk aversion and uncertainty than in the cost-effectiveness criterion used.

A.4 References for Appendix A

A.1 U.S. Nuclear Regulatory Commission, Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, WASH-1400 (NUREG-75/014), 1975.*

A.2 J.L. Sprung, "An Investigation of the Adequacy of the Composite Population Distributions Used in the Reactor Safety Study, SAND 78-0556, 1978.

A.3 U.S. Nuclear Regulatory Commission, Overview of the Reactor Safety Study Consequence Model, NUREG-0340, 1977.**

A.4 J. Miettinen, I. Savolainen, P. Silvennoinen, E. Tornio, and S. Vuori, "Risk-Benefit Evaluation of Nuclear Power Plant Siting," Ann. Nuc. Energy, vol. 3, pp. 489-500, 1976).

A.5 Tennessee Valley Authority, "Browns Ferry Nuclear Units 1, 2, and 3: Effluent and Waste Disposal Semiannual Report, First Half 1979," 1979.

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*Available free upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

**Available for purchase from the National Technical Information Service, Springfield, VA 22161.

APPENDIX B

Application of Risk Acceptance Criteria to Coal-fired Power Plants

B.1 Introduction

To date, probabilistic risk assessment techniques have not been applied to coal-fired power plants on a level comparable to that of nuclear plants. However, an insightful risk study by Morgan, et al [B.1], utilizing a probabilistic methodology to incorporate uncertainties, has been performed for a 1000 MWe coal plant* placed on four hypothetical sites near Pittsburgh, Pennsylvania. Only normal operation of the plant was considered and even as such, not all of the health impacts were assessed. Catastrophic events specific to the plant, such as occur during a severe inversion, as well as catastrophic effects resulting from a family of coal plants, such as severe acid rain or CO_2 buildup, were not considered. Nevertheless, it is instructive to apply the trial risk acceptance framework to the study by Morgan, et al.

Mortality effects from plant-generated sulfates were obtained using the methodology developed at Brookhaven National Laboratory [B.2].

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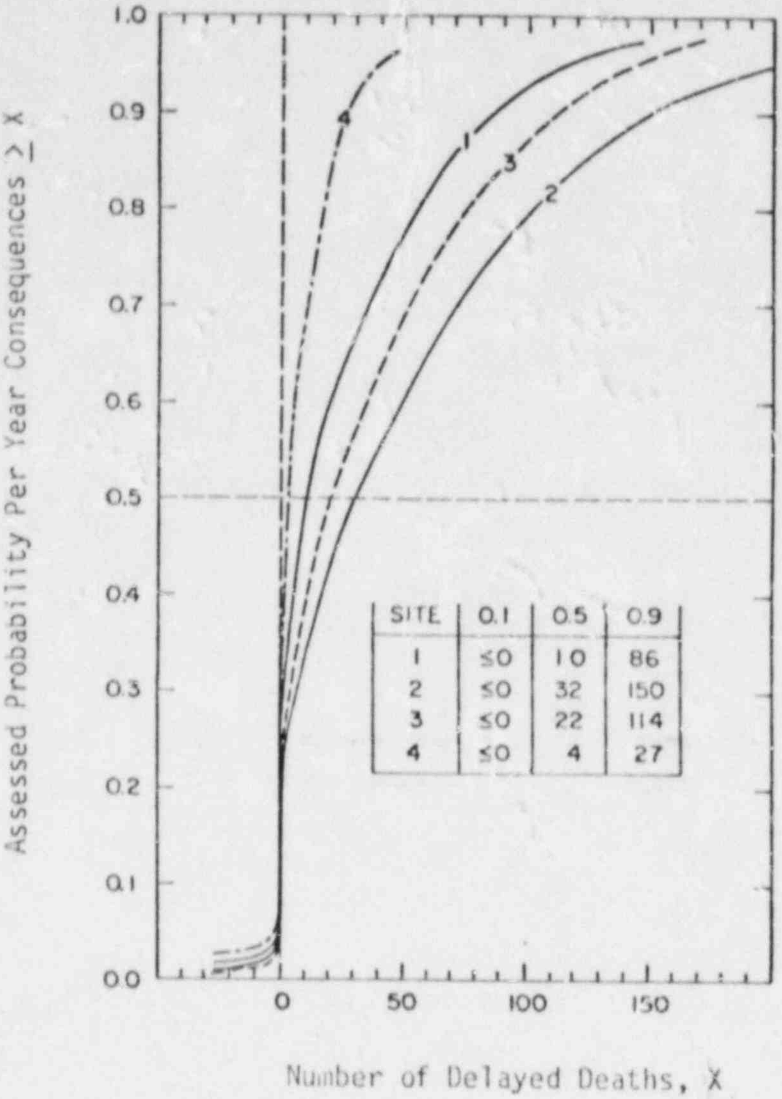
* The hypothetical plant used in the example had a 305 m stack, a stack exit diameter of 8.2 m, exit gas velocity to 16 m/sec, exit temperature of 135°C and a total sulfur effluent rate of 4.15 kg/sec of SO_2. This corresponds to a 1000 MWe plant operating at 38% thermal efficiency with a 75% plant factor, burning 3% sulfur coal with a heat content of 2.9×10^7 J/kg.

Mortality effects due to nitrates, heavy metals, and from interactions among power plant effluents and with other pollutants in the environment may also result, and have not been considered explicitly in these examples (health effects were correlated to sulfate levels). A "subjective probability distribution" for the uncertainty in the various dispersion model parameters, as well as in the damage function, resulted in a set of probability density and cumulative distributions for each site. Identical meteorological data, obtained from the Pittsburgh International Airport, were used for all four sites. For the purpose of this paper, the resulting analyses of these hypothetical plants will be assumed to represent their respective "safety profiles."

The curves shown in Figure B.1 can be used to estimate a measure of the societal risk in terms of the expected value of the number of excess deaths per year. These expectation values, as well as the upper 90% confidence bound are shown in Table B.1. In addition, the average individual risk (societal risk divided by the population) for both cases is also shown.

In this Appendix, the individual and societal risks are examined and compared to the trial criteria of Table 3.1.1. Effects of the ALARA principle and uncertainties are also discussed.



SITE	0.1	0.5	0.9
1	≤0	10	86
2	≤0	32	150
3	≤0	22	114
4	≤0	4	27

FIGURE B.1 Cumulative distributions of the health effects of the four hypothetical coal-fired power plants as modeled by Morgan, et al [B.1]. A first-order estimate of the effect of control can be obtained by multiplying the horizontal axes by ($1 - \eta$), where η is the fractional sulfur removal efficiency.

TABLE 3.1

SOCIETAL AND INDIVIDUAL RISK FOR A 1000 MWe COAL PLANT ON FOUR PENNSYLVANIA SITES

	SITE* 1	2	3	4
Population in 80 km. radius.	2.8×10^6	3.3×10^6	2.9×10^6	6.2×10^5
SOCIETAL RISK (deaths/yr)				
Expected Value	24	49	34	10
Upper 90% Confidence Bound	86	150	114	27
AVERAGE INDIVIDUAL RISK (yr^{-1})				
Expected Value	0.86×10^{-5}	1.5×10^{-5}	1.2×10^{-5}	1.6×10^{-5}
Upper 90% Confidence Bound	3.1×10^{-5}	4.5×10^{-5}	3.9×10^{-5}	4.3×10^{-5}

* From Figure B.1

B.2 Individual Risk

The risks to which an individual located near a coal-fired power plant is exposed are estimated in this section. Risk of early death is not discussed; the risks considered stem from steady state or normal operation (routine release) and thus can be considered to be a chronic societal effect.

One obstacle in calculating the risk to the maximum susceptible (or exposed) individual is effluent pathway modeling; different effluents have a variety of transport properties. Wangen and Williams [B.3] have modeled flyash deposition as a function of distance from a plant in northwestern New Mexico and found a maximum at approximately 3-4 km. Strojan and Turner [B.4] measured trace elements (due to plant effluents) in the soil near a plant in southern Nevada; maximum concentrations of zinc, strontium, copper and nickel were found 4-6 km from the plant. The individual risk is also dependent on the type of coal consumed, the plant characteristics (e.g., stack height) and the site characteristics.

Instructive information on individual risk can be inferred from societal risks. Table B.1 displays the societal risk obtained by integrating the "safety profiles" of the four hypothetical uncontrolled plants discussed by Morgan et al. By simply dividing the societal risk by the size of the exposed population, an average individual risk is obtained; the expected values and 90% confidence of bounds are shown. For site 4, which has the lowest societal risk, these values are 1.6×10^{-5} and 4.3×10^{-5} per year, respectively, for the two confidence levels and represent the highest average individual risk.

If improvements are made to the plant at site 4 such that the expected societal cost is five deaths per year in one case and one death per year in another, the expected average individual risks due to normal operation become 8.1×10^{-6} and 1.6×10^{-6} per year, respectively.

It is of interest to note that O'Donnell and Mauro [B.5] have estimated the risk associated with exposure to air containing gaseous effluents from nuclear and fossil fueled power plants at concentrations equal to the regulatory limits (1977 Clean Air Act). For fossil plants this estimation of maximum individual risk for health effects stemming from sulfur dioxide and particulates is 2.4×10^{-4} per year. The uncertainty in this value is not discussed; the value was qualified as being a relative "index of risk" rather than "an accurate expression of absolute risk." A wide spectrum of achieved emission levels characterize fossil units; and some plants, due partially to their design or type of coal used, operate with emissions only modestly below the levels specified by the standards, while others operate above such standards.

B.3 Individual Risk: Comparison with Risk Acceptance Criteria.

The risks considered in the above analyses are due to normal operation of the facility and thus are manifest by steady state or chronic health insults on society. Such risks may be more properly considered in a distinct category rather than collectively with latent risks from rare occurrences, especially if the former are relatively large risks.

If the estimate of the maximum individual risk given by O'Donnell and Mauro is correct (2.4×10^{-4} per year), then the corresponding facility would not meet the trial criterion specified in Table 3.1.1 for the upper limit for the risk of delayed death (2.5×10^{-5} per year). The assessed expected value of the average individual risk for the four unimproved coal-fired plants (0.86×10^{-5} to 1.6×10^{-5} per year) would meet this upper limit whereas the risks assessed at the nominal 90% confidence level would not. None of the assessed values meet the goal level (5×10^{-6} per year).

Cost effective improvements to the facility may be dictated by society. Estimates of the average risk to the individual of the facility discussed above with improvements are 1.6×10^{-6} to 8.1×10^{-6} per year. These risks would thus approach the goal level. The acceptability would rest on the question of the magnitude of the uncertainties and omissions associated with the analyses.

B.4 Societal Risk

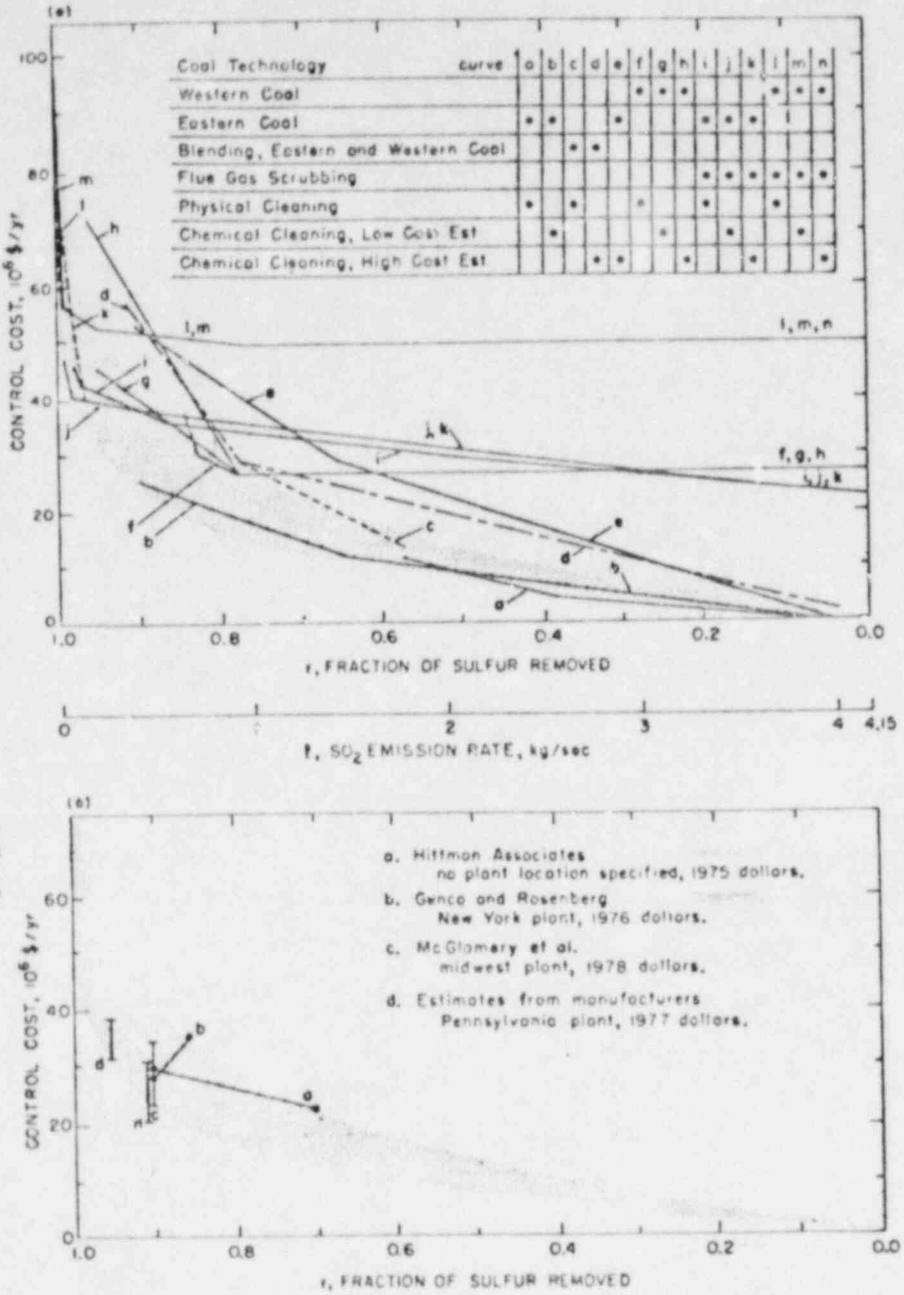
As stated above, the curves in Figure B.1 can be mathematically manipulated to estimate societal risk. These values, shown in Table B.1, can also be used to further illustrate the framework of the proposed risk acceptance criteria.

Only the societal risk estimate given by the expected value for site 4 would satisfy the trial criterion of 10 deaths per year. If applied at the upper 90% confidence limit, none of the sites would meet the criterion.

The application of risk aversion was not attempted because: a) the effective social cost would become very large even for small values of the risk aversion weighting factor, and b) society does not appear to be risk averse to coal-fired plants because the consequences are, to date, of a chronic nature. The use of the ALARA concept, however, can be illustrated.

In Table B.2, the fraction of sulfur removed, the cost (from Figure B.2), and the cost per death averted is shown for several control strategies. These sulfur control strategies were chosen to reduce the societal risk of sites 1, 2 and 3 to that of site 4 (which meets the trial criterion at the expected value), both at the expected value and at the upper 90% confidence bound. Although sites 1, 2, and 3 do not meet the societal risk acceptance criterion, the ALARA is applied for illustrative purposes.

If a $2 million per death averted criterion is used, all improvements would be cost-effective if the criterion were the only consideration. If a $0.6 million per death averted criterion is used, only site 2 would be improved at the expected value, and all sites would be improved at the upper 90% level. Note that a strict application of



Coal Technology curve	a	b	c	d	e	f	g	h	i	j	k	l	m	n
Western Coal						●	●	●				●	●	●
Eastern Coal	●	●			●				●	●	●			
Blending, Eastern and Western Coal			●	●										
Flue Gas Scrubbing									●	●	●	●	●	●
Physical Cleaning	●		●			●			●			●		
Chemical Cleaning, Low Cost Est		●					●			●			●	
Chemical Cleaning, High Cost Est				●	●			●			●			●

FIGURE B.2 ESTIMATES OF CONTROL COSTS FOR SULFUR REMOVAL FOR A NUMBER OF ALTERNATIVE CONTROL STRATEGIES [B.7]. THE SHADED AREA REPRESENTED A NOMINAL 90% CONFIDENCE INTERVAL [B.6].

TABLE B.2

FRACTIONAL REDUCTION, COST AND COST PER DEATH AVERTED FOR VARIOUS SULFUR CONTROL STRATEGIES

STRATEGY*	FRACTION OF SULFUR REMOVED	COST ($/yr)	COST PER DEATH AVERTED ($/death averted)
		AT EXPECTED VALUE	
1 → 4	0.58	15 million	1.07 million
3 → 4	0.71	18 million	0.75 million
2 → 4	0.80	22 million	0.56 million
		AT 90% UPPER CONFIDENCE BOUND	
1 → 4	0.68	18 million	0.30 million
3 → 4	0.76	20 million	0.22 million
2 → 4	0.82	23 million	0.19 million

* Reducing the societal risk from the plant at sites 1, 2 and 3 to that of site 4.

the criterion, as specified by the framework, would involve determining cost-effective improvements only after the societal risk goals have been met.

The ALARA principle can be used to determine the level of sulfur control that would be cost-effective at site 4. Since the calculated expected value of 10 deaths per year meets the societal risk criterion, the use of the ALARA principle, as advanced by the framework, can be illustrated. In Table B.3, the cost per death averted for site 4 is shown as a function of the number of deaths averted, for both the expected value (10 deaths per year) and the upper 90% confidence bound (27 deaths per year). At the expected value, up to an additional 5 deaths per year can be averted if a $2 million per death averted cost-effectiveness criterion is used at a total cost of $10 million per year. At the 90% confidence bound, up to 26 deaths per year should be averted, at a cost of $52 million per year. It is interesting to note that if the criterion was set at $0.6 million per death averted (the implicit value in the new source performance standards [B.6]), no improvement would be required at the expected value* and only a 30% reduction in sulfur would be required at the 90% upper confidence bound.

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* The cost per death averted is $2 million for all values below 0.50 because the slope of the curve in Figure B.2 is constant in that range.

TABLE B.3

FRACTIONAL REDUCTION, COST AND COST PER DEATH AVERTED FOR PLANT #4 FOR VARIOUS SULFUR CONTROL STRATEGIES

DEATHS/YR AVERTED	FRACTION OF SULFUR REMOVED	COST ($/yr.)	COST PER DEATH AVERTED ($/death averted)
	AT EXPECTED VALUE*		
4	.40	8 million	2.0 million
5	.50	10 million	2.0 million
7	.70	18 million	2.5 million
9	.90	38 million	4.2 million
	AT 90% UPPER CONFIDENCE BOUND*		
8.3	.31	5 million	0.60 million
13.5	.50	10 million	0.75 million
20	.75	20 million	1.0 million
25	.92	40 million	1.6 million
26	.96	52 million	2.0 million

* Expected value is 10 deaths per year, at 90% upper confidence bound the risk is 27 deaths per year.

Lastly, the fractional sulfur reduction, cost, and cost per death averted were calculated for sulfur control strategies in which mortality at sites 1, 2 and 3 (as is) are made comparable to an improved site 4. At the improved site 4, the residual societal risk after applying the criterion at the expected value and upper 90% confidence bound is 5 deaths per year and 1 death per year, respectively. All improvements are justified if the criterion is $2 million per death averted. If the $0.6 million per death averted guideline is used, the only cost-effective control strategy is 2 → 4i at the upper 90% confidence bound. See Table B.4.

Once again, proper attention needs to be paid to the identification and incorporation of omissions and uncertainties in the assessment of societal risks. If the economic component of the ALARA were included, as specified in the companion framework [B.8] to account for such impacts as those due to acid rain, the allowable costs for improvement would be greater. In fact, they may dominate the determination in many cases.

TABLE B.4

FRACTIONAL REDUCTION, COST AND COST PER DEATH AVERTED FOR VARIOUS SULFUR CONTROL STRATEGIES

STRATEGY*	FRACTION OF SULFUR REMOVED	COST ($/yr)	COST PER DEATH AVERTED ($/death averted)
	AT EXPECTED VALUE		
1 → 4i	0.80	22 million	1.2 million
3 → 4i	0.85	26 million	0.9 million
2 → 4i	0.89	37 million	0.84 million
	AT 90% UPPER CONFIDENCE BOUND		
1 → 4i	.99	80 million	0.94 million
3 → 4i	.99	80 million	0.70 million
2 → 4i	.99	80 million	0.54 million

* Reducing the societal risk from the plant represented by curves 1, 2 and 3 to that of an improved curve 4i. At expected value, the improved curve 4 risk is 5 deaths per year, at the 90% upper confidence bound the improved curve 4 risk is 1 death per year.

B.5 References for Appendix B

B.1 M.G. Morgan, S.C. Morris, A.K. Meier and D.L. Shenk, "A Probabilistic Methodology for Estimating Air Pollution Health Effects from Coal-fired Power Plants," Energy Systems and Policy, vol. 2, pp. 287-310, 1978.

B.2 Brookhaven National Laboratory, "The Role of Sulfate Emissions from Fossil Fuel Consumption." progress reports, 1976

B.3 L.E. Wangen and M.D. Williams, "Elemental Deposition Downwind of a Coal-fired Power Plant," Water, Air, and Soil Pollution, vol. 10, pp. 33-44, 1978.

B.4 C.L. Strojan and F.B. Turner, "Trace Elements and Sulfur in Soils and Plants Near the Mohave Generating Station in Southern Nevada," Proc. 4th Joint Conf. on Sensing of Environmental Pollutants, New Orleans, pp. 537-540, 1977.

B.5 E.P. O'Donnell and J.J. Mauro, "A Cost-Benefit Comparison of Nuclear and Nonnuclear Health and Safety Protective Measures and Regulations," Nuclear Safety, vol. 20, pp. 525-540, 1979.

B.6 M.G. Morgan, W.R. Rish, S.C. Morris, and A.K. Meier, "Sulfur Control in Coal Fired Power Plants. A Probabilistic Approach to Policy Analysis," J. Air Pollution Control, vol. 28, pp. 993-997, 1978.

B.7 G.C. Ferrell, "Coal Energy and the Environment: Analysis of Economic and Energy Efficiency Implications of Environmental and Resource Constraints on the Utilization of Coal to Produce Electricity," PHD Thesis, University of California, Berkeley, 1977.

B.8 J.M. Griesmeyer and D. Okrent, "Risk Management and Decision Rules for Light Water Reactors," Part 2 of this report.

APPENDIX C

Application of Risk Acceptance Criteria to the Canvey Island Industrial Complex

C.1 Introduction

In 1978 the Health and Safety Executive of the United Kingdom issued the report of a study which assessed the risks associated with the various industrial activities on Canvey Island and the neighboring portion of Thurrock along the Thames River in England [C.1]. Only accident scenarios were included; risks rising from normal operation were not.

The area considered measured approximately 9 miles long by 2.5 miles wide. In 1978 the estimated population of Canvey Island was 33,000. The island also retains its historic function as a vacation retreat.

The industrial activities in the study area include:

- tank storage facilities. Two large tank farms exist; one of 80,000 metric tons capacity handling petroleum products and another of 300,000 metric tons which handles a variety of substances including petroleum but also materials which are flammable or toxic.
- a methane terminal. The primary purpose of this facility is the importation and storage of LNG. Storage capacity is 100,000 metric tons; approximately 50 shipments of 12,000 tonnes each arrive at this facility annually. Liquefied butane is also stored at the facility.

- oil refineries. The two existing refineries have a combined storage capacity of 5,000,000 metric tons. Liquefied ammonia (14,000 tonnes) is also stored at one of these sites. Two additional oil refineries are proposed.
- a liquefied petroleum gas cylinder facility. This facility includes 7 storage tanks with a total capacity of 305 tonnes, as well as a large number of portable gas cylinders.
- an ammonium nitrate processing facility. This activity involves the storage of 1900 tonnes of liquefied ammonia.

Most shipments of materials arrive by sea. Products and trans-shipments are transported out by sea, road and rail. Related activities include the nearby transshipment of petroleum and explosives as well as normal traffic on the Thames River.

The Health and Safety Commission's report professed that the assessed probabilities and consequences are generally realistic, may err on the side of pessimism by a factor of two or three, but are unlikely to be in error by as much as a factor of ten. Quantitative confidence levels are thus not given; however, several specific detailed analyses were recommended to be performed to further identify weaknesses in the existing safety arrangements. Where practical, the degree of subjectivity employed was indicated via flagging (e.g., the subscript "a" would indicate a risk assessed from historical data; "d" would indicate a parametric value from a subjective argument). Thus, those estimates for which sensitivity analyses are most important were made apparent in the original report.

Societal risks were presented via complementary cumulative distribution functions giving the number of early deaths for all existing facilities and for proposed new facilities, as well as in nonaggregated form. Individual risks were presented as upper limits and specified for seven predefined geographical regions of the study area. In addition, societal and individual risks were presented which take into account improvements identified by the study.

This Appendix appraises the assessed individual and societal risks of the Canvey Island area industrial complex with respect to the trial risk acceptance criteria. The aggregate form of the societal risk is utilized in this illustration.

C.2 Individual Risk

Individual risk of acute death were presented for seven regions comprising the residential portions of the study area. Five of these regions represent Canvey Island proper and one region each describes South Benefleet and Stanford le Hope. With the exception of one of the regions on Canvey Island which contains primarily vacation property, individual risks were assessed assuming 24 hr/day occupancy. As indicated above the values given are, in a sense, upper limits and may tend to err on the side of pessimism when applied to a given individual. However, the form of the analyses would seem to indicate that the calculations would not greatly overestimate the risk to a "maximum exposed individual."

The aggregate individual risks for the existing and proposed facilities are shown in Table C.1. In the final stages of the investigation, further improvements were identified that, if implemented, would yield a lower estimate of the average individual risk at Canvey Island (from 5.3×10^{-4} per year to 1.4×10^{-4} per year).

The highest risks are experienced by those people residing in Region A of Canvey Island. Their estimated risks due to existing endeavors with and without facility improvements are 1.3×10^{-3} and 6.1×10^{-4} per year, respectively. At the other extreme, the residents of South Benfleet experience the lowest corresponding individual risks: 1×10^{-4} and 3×10^{-5} per year, respectively.

C.3 Individual Risk: Comparison with Risk Criteria

The trial criterion from Table 3.1.1 for the upper limit of the risk of early death is 2.5×10^{-5} per year. The risks associated with the existing facilities in each of the study regions, even with identified improvements, were assessed to be in excess of this criterion unless the risks are overestimated by factors ranging from 1.2 to 50. Note that omissions in the analyses (e.g., concerning those hazards resulting in delayed effects as well as risks due to normal operation) exist and that only a qualitative treatment of uncertainties has been made.

C.4 Societal Risks

The societal impacts for specified populated areas, presented in the form of complementary cumulative distributions of cases of early

TABLE C.1

UPPER LIMITS ON THE AVERAGE RISK OF ACUTE DEATH DUE TO THE CANVEY ISLAND INDUSTRIAL COMPLEX*

AREA	REGION	EXISTING FACILITIES	EXISTING AND PROPOSED FACILITIES	EXISTING AND PROPOSED FACILITIES WITH IMPROVEMENTS
Canvey Island	A	1.3×10^{-3}	2.6×10^{-3}	7.7×10^{-4}
	B	4.7×10^{-4}	5×10^{-4}	4.1×10^{-4}
	C	3.9×10^{-4}	8.7×10^{-4}	2.6×10^{-4}
	D	3.1×10^{-4}	3.6×10^{-4}	1.8×10^{-4}
	E	1.9×10^{-4}	2.4×10^{-4}	7×10^{-5}
	Average	5.3×10^{-4}	---	3.4×10^{-4}
Stanford le Hope	F	5×10^{-4}	5.2×10^{-4}	1.3×10^{-4}
South Benfleet	G	1×10^{-4}	1.6×10^{-4}	4×10^{-5}

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*Data from reference [C.1], all units yr^{-1}

death, were evaluated for each facility. Proper application of the criteria would require the consideration of the aggregate site risks as well as those from each facility. For illustrative purposes however, societal risks were treated in an aggregate form only. Four cases are considered:

- all existing facilities,
- all existing facilities with identified improvements,
- all proposed developments, and
- all proposed developments with identified improvements.

The authors of the Canvey Island study qualitatively placed a high level of confidence in their analyses of societal risks. That is, they believe the risks were overstated based on the nature of the historical data employed. They also believe that the use of statistical data rather than subjective data would not lead to a reduction of the estimate. Evacuation was included in the modeling, where applicable; some degree of interaction between facilities was also included. Credit for the application of future experience was not taken.

The expected social costs for the four test cases are shown in Table C.2 in units of deaths per year. Again, a simple power-law model, with exponent α, was used to express risk aversion. Recall that $\alpha = 1$ yields the expected value of the consequence per unit time (the calculated risk); $\alpha > 1$ yields a measure of risk aversion and $\alpha < 1$ indicates risk perference. If the uncertainties in the values shown are small, then the trial criterion from Table 1.1 would accept only the existing facilities, if no improvements were to be made, and $\alpha = 1$ (no risk aversion). For $\alpha = 1.5$, the complex, with or without improvements, would violate the criterion. Note that if $\alpha = 0.5$ (a "risk seeking" society), then no improvements would be suggested by the criterion.

C.5 Application of Cost Effective Risk Reduction

As shown in Table C.2, the expected social cost in deaths per year has been estimated for the Canvey Island complex as constructed and operating, and with potential improvements. In addition, proposed additional facilities with and without improvements were considered. The use of an ALARA (As Low As Reasonably Achievable) requirement can be illustrated, to see if these improvements are cost effective.

Since no cost estimates were given for these potential improvements, one can assess what costs are allowable, given a cost-effectiveness criteria. Figure C.1 shows the maximum expenditure as a function of "effective" deaths averted per year.

From Figure C.1 the following can be illustrated for a \$2 million per death averted cost-effectiveness criterion:

(1) Without risk aversion ($\alpha = 1$), the maximum cost-effective expenditure would be \$9 million per year for improving all existing facilities and \$7.2 million per year for improvements in the proposed new facilities.

(2) With risk aversion at $\alpha = 1.5$, an expenditure of up to \$644 million per year would be cost-effective for improving

TABLE C.2

CALCULATED EQUIVALENT SOCIAL COSTS OF CANVEY STUDY CASES (in deaths per year) AS GIVEN BY SIMPLE POWER-LAW RISK AVERSION MODEL

α*	ALL EXISTING FACILITIES	ALL EXISTING FACILITIES WITH IMPROVEMENTS	PROPOSED FACILITIES (ONLY)	PROPOSED FACILITIES WITH IMPROVEMENTS
0.5	0.12	0.04	0.07	0.01
1 (calculated expected value)	7.1	2.6	4.1	0.5
1.5	512	190	267	32
2	42083	15694	19440	2233
frequency (yr^{-1}) of events with consequences $\geq$ 10 deaths	3.0×10^{-3}	1.0×10^{-3}	1.5×10^{-3}	2.0×10^{-4}

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* Alpha is the exponent in the power-law risk aversion model. With $\alpha = 1$ the calculated expected value of the social cost is obtained; for any other value of α, an "equivalent" social cost is obtained.

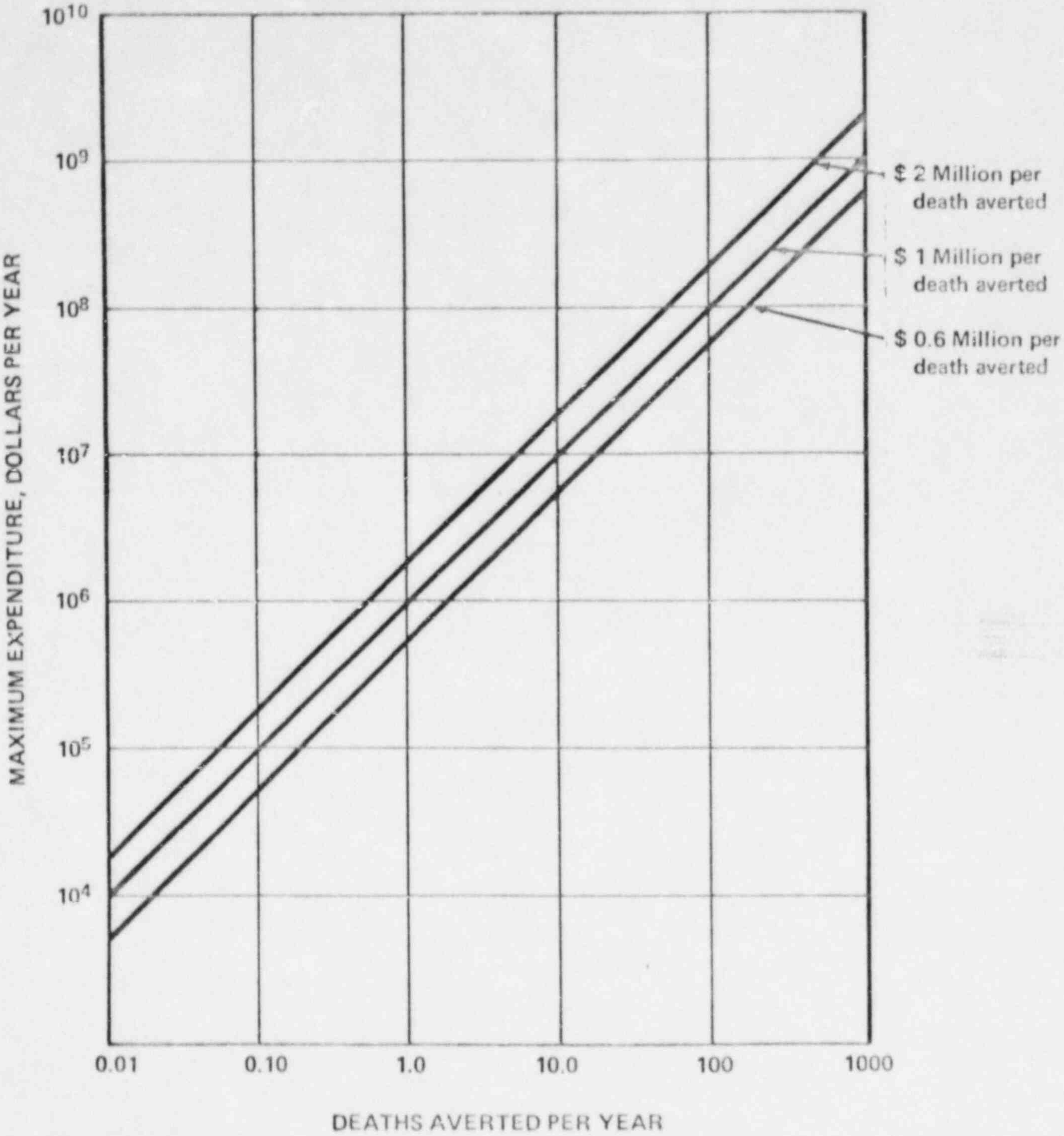

Figure C.1 Maximum Expenditure as a Function of Deaths Averted (Real or Equivalent) and the Value Assigned to the Cost-Effectiveness Criterion.

all existing facilities and \$470 million per year would be cost-effective for the new facilities.

(3) With risk aversion at $\alpha = 2$, the permitted costs run into the tens of billions of dollars for the potential improvements.

The introduction of uncertainty into the application of a cost-effective risk reduction requirement, produces the same effect as the introduction of risk aversion. If the expected social costs are uncertain by a factor of 10, the maxmium cost-effective expenditure would go up by the same factor of 10. Similiarly, if the cost-effectiveness criterion were to be decreased by a factor of 2, the maximum "cost effective" expenditure would decrease by a factor of 2.

Lastly, with $\alpha = 0.5$ (risk seeking society) the maximum cost-effective expenditure drops to several tens of thousands of dollars (i.e., if it would cost more than \$160,000 for improving all existing facilities), then the improvements are not warranted.

C.6 Discussion

Hazard indices can be defined specifically for each technological endeavor. Generalized hazard indices can be defined, but would be of limited utility in the abstract. Nevertheless it is informative to consider analogous forms of hazard indices as part of a risk assessment. Table C.2 shows such a hazard index: the frequency of events with consequences greater than 10 (unweighted) deaths/year. Alternatively the Canvey Island study indicates the probability of a "significant accident" (some of which have no associated fatalities) as approximately 3×10^{-2} per year. The acceptability of an endeavor may rest on such measures of incident frequency analogous to degraded core damage hazard states for a nuclear unit; such considerations are, however, beyond the scope of the simple trial criteria.

The risk, as assessed, of the Canvey Island industrial complex would be in excess of that specified by the trial criteria. Benefits of the complex have not been considered; indeed, the complex is considered vital to England and continues to operate. Also, it has not been determined whether it is either possible or practical to construct an equivalent complex that would conform to the criteria. Nevertheless, it is reasonable to expect such a facility would present a reduced spectrum of risks and that the trial criteria would provide at least adequate protection to the public health and safety, if the societal benefits of the facilities are equivalent.

C.7 Reference for Appendix C

C.1 Health and Safety Executive (UK), "Canvey: An Investigation of Potential Hazards from Operations in the Canvey Island/Thurrock Area," London: Her Majecty's Stationary Office, 1978.

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ABSTRACT: A possible approach to quantitative safety goals for nuclear power plants is provided by the Advisory Committee on Reactor Safeguards. The report contains three parts: 1. A review of several proposals for quantitative risk criteria. 2. A preliminary proposal for a possible approach to quantitative safety goals. 3. A brief evaluation of several technologies, including nuclear, in terms of the proposed criteria. The trial approach to quantitative safety criteria is divided into two major tasks: The first is the predominantly social and political problem of setting the safety criteria, which are termed decision rules; the second is the technical question of estimating the risks and deciding whether the safety criteria have been met.

The proposed numerical valves for use in decision rules are intended to simulate further discussion and evaluation leading to the future development of suitable risk acceptance levels.

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

July 8, 1982

MEMORANDUM FOR: Chairman Palladino
Commissioner Gilinsky
Commissioner Ahearne
Commissioner Roberts
Commissioner Asselstine

FROM: Forrest J. Remick

SUBJECT: PUBLIC COMMENTS ON PROPOSED SAFETY GOALS

In my memorandum of July 7, 1982, I attached a copy of the "Summary of Comments" on the proposed Safety Goals. I also indicated that other documents are being prepared for the July 14, 1982 discussion of Safety Goals and Implementation Program. A copy of the "Abstract of Comments" is attached.

Enclosure:
As stated

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ABSTRACT OF COMMENTS

The "Summary of Public Comments" (in which each respondent is identified and the response summarized) is voluminous and does not provide a convenient means for discerning the overall nature of the comments. Because of this, OPE has prepared the following "Abstract of Comments." The format is the same as the Summary, i.e., eight sections summarizing comments on the principal parts of the proposed policy statement and nine sections summarizing the responses to the questions posed by the Commission at the end of the proposed policy statement.

Although the "Abstract of Comments" is intended to be an accurate representation of the oral and written comments that have been received, it may not faithfully reflect the respondents' views. Moreover, the abstractors, in the interest of brevity, have included few details of the commenters' discussions of the reasons for their views. The reader who finds the abstract unclear and wishes to know exactly what the commenter said should consult the "Summary of Public Comments" or the original responses themselves.

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1. OVERALL REACTION TO PROPOSED SAFETY GOALS

Reactions to the proposed safety goals range from enthusiastic praise and endorsement to vigorous rejection accompanied by derogatory remarks. The extreme reactions at both ends of the range are of limited value in terms of preparing a revised policy statement. The many intermediate reactions - endorsements with rationalized rejections and suggested changes - are valuable in revealing what many respondents expected of the safety goals and how they would wish to modify the goals to satisfy their expectations. These reactions provide a useful basis for considering revisions to the draft to enhance its acceptability by a broader segment of the interested public.

As the following summary indicates, the reactions of respondents within certain categories (such as the utilities and the nuclear industry and professional groups) are more consistent and easier to categorize than the reactions of individual members of the public.

The Utilities

The utilities' responses are almost unanimously supportive of the proposed safety goals. Many repeat the purposes included in the proposed policy statement, i.e., the safety goals

- will clarify NRC's position on "how safe is safe enough?"
- will lead to more coherent, consistent regulation and a more predictable regulatory process
- will aid public understanding of and confidence in the safety of nuclear power plants
- will help utilities evaluate safety-cost tradeoffs to achieve an optimum balance

The utilities note the following additional reasons for adopting the safety goals:

- will ultimately allow for a better focusing on the issues of true safety significance, rather than the present practice of treating all issues alike (120, C10)
- is a necessary first step toward the resolution of such matters as the severe accident rule, many unresolved safety issues, and the conduct and objectives of the NREP program (11[illegible]
- represents a first step in removing the subjectivity that many feel is characteristic of the current licensing process (127)
- will rationalize the regulatory process and maximize the safety benefits obtained from expenditure of available resources (98)

A number of the utilities express misgivings about the value and practicality of the goals until more is known about the standards to be used for demonstrating compliance and the plan that is developed for implementation. Many express reservations about the wisdom of publishing safety goals for nuclear power to the exclusion of comparable goals for other activities.

Some responses are less than endorsements and include reservations, such as:

- hoping that the adoption of the safety goal will lead to a backfitting policy based on consideration of overall safety rather than the current practice of focusing on systems or components (126)
- hoping that the safety goals will lead to a rational differentiation between regulatory requirements for new plant designs and operating plants (126)
- noting that the development of safety goals will require concurrent development and identification of an acceptable methodology such as probabilistic risk assessment that provides a safety "yardstick" suitable for determining whether safety improvements are required (98)
- believing that the use of goals in the regulatory process must be subject to right-of-challenge by industry (122)
- noting that, unless there are clear-cut criteria by which compliance can be shown, a derogatory implication would be added to an already conspicuously berated industry without just cause (69)
- suggesting that the public welfare might better be served by a comprehensive comparison of risks and benefits of the various alternatives (140)

The Nuclear Industry and Related Professional and Industry Organizations and Individuals

The various architect-engineer firms, major vendors, and professional societies almost all endorse the safety goals. Many of the responses advance the same supportive arguments as the utilities. For example, Chauncey Starr, EPRI, believes that "The NRC's endeavor is the only way to provide an explicit means for constructive exchange between the nuclear industry and the NRC and to disclose all the factors involved in decision-making." (32)

In addition, the following points are made:

- several aspects of the policy statement lead to the belief that issuance as a final policy statement is premature at this time (128)
- adoption of the statement should not precede an assessment of how it can be implemented and what positive and negative benefits will result (94)
- the instant policy is overly stringent and is based on reducing a remote hypothetical risk to essentially zero (94)
- safety goals for nuclear power plants should be set up in accordance with other technical regulation of our society, i.e., a minimum of risk is only achieved if the same goals is established for all technical equipment (132)
- the goals should reflect the actual, not perceived, risk to the public (B10, B17)

Academics and professionals

Relatively few academics and professionals testified at the hearings or responded to the draft policy statement. The respondents divided into two groups: On the one hand, there were those who believed that the safety goals were a "timely effort" (90) and a "large step in the right direction" (133) that would produce a workable set of goals that might serve as a "model for other technological activities that are regulated." (89) On the other hand, the second group believed that the formulation of safety goals by NRC was an "illusion to create public confidence" and that the goals were too vague and abstract and too devoid of an implementation plan to be useful. (31) Several in the latter group also believed that the safety goals should include risks from routine emissions, the nuclear power plant cycle, waste management, sabotage, diversion of nuclear materials, transportation, etc. (77) One commenter believed that the goals omitted the alternative of moderating population growth around nuclear plants and contained a potential data problem involving individual site area population. (11)

The reactions of this group in general reflected the comments expressed by the Committee on Nuclear Technology and Law, American Bar Association of New York (109), which stated in part "Before numerical guidelines can play a significant role in reactor safety activities... it will be necessary for the Commission to agree upon a more uniform and predictable method of application of probabilistic risk assessment concepts." They also reflected the views of Alvin Weinberg, Oak Ridge Associated Universities (47), who considered the quantitative safety goals to be "valuable design criteria" but believed that the goal statement was deficient in at least three important respects: (1) "the quantitative goals do not form a consistent set potentially useful for design or licensing," (2) "the objective of the policy statement is too vague," and (3) "there is no implementation plan."

State Legislators

Only a few state representatives responded. The comments ranged from positive ones, such as "excellent and acceptable starting point" (115) to negative ones including:

- illusion to give public confidence (B3)
- fails to deal with major safety issues attached to operation of nuclear power plants; hence the title is misleanding (B12)
- comparing deaths from nuclear accidents to other means of death is totally incomprehensible. (B2)

Private Citizens

The vast majority of commenters were private citizens who were representing their own positions. Although some of them were associated with groups of various persuasions (e.g., environmental, anti-nuclear, pro-nuclear, etc.) their comments reflected their individual - rather than the group - point of view.

The most popular themes expressed by the individuals, most of them having an antinuclear bias, concerned the following points (listed in general order of frequency of articulation):

- the "limited" scope of the "omissions" inherent in the proposed safety goals. Many individuals believed that it was both improper and unwise to consider nuclear safety without looking at such issues as worker safety, waste problems, fuel cycle effects, routine radioactive releases, nuclear material diversion, earthquakes, sabotage, and intergenerational transfers of risks. One commenter noted that risk of psychological damage should be included. Another commented that risks to forms of life other than human beings are ignored.

- the "general, vague" quality of the goals. Many individuals agreed with Commissioner Gilinsky that "the proposed guidelines were too remote from the nitty gritty hardware decisions that have to be made every day... to be of much use." They pointed out that the goals were too abstract to be meaningful, bore "no demonstrable connection to practical reality" and did not provide a realistic way to assure health and safety of the public.

- Too little emphasis on enforcing quality, or improving engineering principles and practices and on improving safety. It was suggested that "real safety comes from good design of facilities, good construction (and) good fabrication."

- Substantial variations exist in individual perceptions regarding the "acceptable" level of risk. Commenters questioned the acceptability of risk limits as high as those specified in the report and stated that greater emphasis should be placed on zero population risk - on the prevention of deaths from public safety accidents. These commenters objected to goals that "would permit 13,000 deaths over the lifetime of 150 reactors" or the likelihood of "murder" of large numbers of people. One commented that "acceptable risks means acceptable deaths since nuclear plants will always be operated up to their maximum capacity."

- Objection to qualitative goals. Closely tied to the notion of zero risk was the oft-stated belief that the use of numerical guidelines might be a source of misinformation - to connote standards or levels of acceptability in the public mind. One commenter asked, "Does proposing a limit on core meltdown probability make it less likely?"

- The purpose for which the guidelines were to be used. Commenters foresaw problems with using probabilistic risk assessment (PRA) to define safety aspects of nuclear power plants on the basis that it would be impossible to factor in or calculate human error, poorly trained operators, inadequate maintenance, multiple failures, etc. These individuals saw no assurance of safe operation until "human behavior" problems were resolved. Further problems with the use of PRA concerned the belief that information on goals would become inaccessible to independent review by the public. As one commenter stated: "Complex and unverifiable computer programs inaccessible to the independent reviewer will substitute for basic judgment in safety regulation." And again "any reliance on PRA to provide a good basis for a safety goal must be counterproductive or so undisciplined as to be worthless." Some noted the inconsistency between use of PRA and NRC repudiation of WASH-1400.

- Many individuals stated that comparisons are misleading; that "nuclear power poses a unique kind of risk." And that their risks cannot be compared with other types of energy plants. These commenters believe that the societal risk of nuclear power, with its more hazardous technology, could not be compared with other electricity-generating techniques. Many commenters pointed out that the draft safety goals ignored alternatives to electricity for supplying our needs, particularly "conservation which makes any expansion in generating ability unnecessary." These individuals questioned the taking of chances when "safer alternatives exist." Some individuals believed it would be desirable to have a historical backup of recorded deaths and injuries (or lack thereof) from nuclear energy production as compared to other forms of electricity production. Others thought that the safety goals should take into account the "plausible level of individual exposures as determined by realistic calculations."

- Many individuals perceived the draft safety goals as "window dressing, an effort to assuage public fears, daily increasing, concerning accidents at nuclear power plants." Some saw it as a "statement in defense of the indefensible; a transparent fraud;" and/or "play designed to mask specific issues related to nuclear power safety with a smoke screen based on PRA." Others saw it as an "exercise in futility", and a "cover-up of deadly nuclear hoax," and "an attempt to improve public perception of nuclear safety instead of preventing risks." One suggested that NRC should not waste its time trying to convince the public that nuclear power is safe.

- Many individuals advocated that we should cease building plants to achieve ALARA risks; that the reliability of nuclear plants remains so uncertain that there is no way to assure safety.

- Some individuals thought the safety goal statement should include risk factors for the "non-biologically average" members of the public, such as infants, children, and pregnant women.

- Finally, individual comments covered the following points:

  - -- NRC should look at its siting practices and identify risks at each specific site

  - -- NRC should examine "unexpected" malfunctions; PRA doesn't take them into account

  - -- safety goal statement is an "elitist" statement and "will not reach a broad spectrum of people"; it is "premature and overly specific," and would be better if it were limited to clear understandable qualitative considerations

  - -- the statement "widens the gap between theoretical work in probabilistic risk assessment and experience in the field."

  - -- Risks addressed by safety goals are not as extensive as actual risks nor are they based on realistic accident scenarios; they should include risks of evacuation as well as the risks of ingesting contaminated food, milk, water as these may contribute more man-rem than exposure to the plume.

  - -- Authors of safety goals have a risk-benefit mindset that is philosophically bankrupt

  - -- An honest and clear description of all costs involved in generating electricity by various means and their related health and safety risks should be presented to the public, and the people that would be receiving nuclear power should determine if the risks are acceptable.

  - -- NRC's function is not to determine acceptable risk but to make certain that accidents do not occur; if it's impossible to avoid accidents, NRC should see that the plants are closed down and decommissioned safely

  - -- There is no place for nuclear power plants in a free society; they should be shut down as they will surely kill us and poison the land

  - -- Detonation of a nuclear weapon on a nuclear power plant, whether intentional or unintentional (e.g., intended for a nearby military installation such as the Vandenberg Air

Force Base near Diablo Canyon), would create an enormous catastrophe; nuclear plants should be shut down.

-- Nuclear power should have no subsidies and no regulations and be required to compete with other forms of power generation

-- As long as private corporations run nuclear plants while looking for profit the plants are going to be unsafe

-- Nuclear plants should be built into a mountain or located underground to reduce risk

-- Fatalities already caused by release of low-level radiation are not taken into account

-- Waste problem should be solved before building nuclear plants

-- PRA-based safety standards may thwart nuclear power developments; failure to build nuclear power plants have already cost millions of lives

2. IMPLEMENTATION OF GOALS

Nineteen commenters stated they would need to review the implementation plan before they could fully comment on the Safety Goals. (121, 122, 112, 92, 117, 116, 58, 68, 128, 100, 110, 56, 70, 47, 142, C21, C16, 32, L20). The following comment by the American Nuclear Society is representative of the views of this group:

> Judgments on the value of a safety goal approach cannot be made by consideration of the goals themselves apart from consideration of the implementation process. Certainly the safety goals are devoid of much meaning without a clear specification of how it will be established that the goals are met. It is clear that implementation of the safety goals approach must be made in a cautious and enlightened manner.
>
> For the above reasons, the endorsement of the ANS to the safety goal approach, while unqualified in principle, must remain with some reservations until the value of the approach, as actually implemented, is validated. (117)

Five commenters believe that the goals should not be used in licensing, but only to assess regulations. (101, 114, 70, 72, 81). Detroit Edison's comment summarizes this group's views:

> The safety goal should be the standard against which both existing and future rules and guidelines are measured. To ensure consistency and order of the regulatory process, these rules and guidelines, and not the safety goal itself, should be applied in individual licensing activities. (101)

Five commenters agreed that the safety goals should be used on a trial basis. (127, 120 + C10, 104, 136, 139). The comment of Alabama Power provides an example of this position:

> Alabama Power Company concurs with the plan to provisionally adopt the proposed, or amended, safety goals. Since the concept of safety goals and the methodology for determining compliance has not been used in the past, provisional adoption will allow the ideas to be

> tested and developed without impacting the licensing of nuclear power plants if problem areas are identified. Provisional use would only be for the purpose of determining viability of the safety goal concept and would not be the basis for actual licensing or backfit decisions. After provisional use of these goals and guidelines, this subject should be reopened for public comment. (127)

Four commenters thought that the safety goal should only be a tool to supplement current requirements. (130, C10 + 120, 126, 136). The comment by Portland General Electric reflects the views of this group:

> It is important to realize that any numerical guidelines adopted now cannot be "hard and fast," since the risk assessment methodology and supportive data base are as yet not fully refined. The uncertainties associated with any analysis must be taken into consideration, and thus, it is best to rely on risk assessment techniques to provide supplementary information for consideration in the regulatory process. (130)

Three commenters believe there needs to be a better consensus on the usefulness of PRA before it can be used in the implementation of the safety goals. (98, 133, 47). The following comment by Baltimore Gas and Electric provides examples of the reasoning behind this position:

> It may be premature to insist on the application of PRA to the determination of compliance with the safety goals suggested, or even compliance with the suggested risk guidelines. Because these are expressed as a relationship of risk to risk, they provide a reasonable basis for expressing and clarifying NRC regulatory policy in absolute terms, independent of assessment methodology. Without a broader technical consensus on the precision of PRA results, the question of whether existing plants meet these goals will not be directly resolved by PRA. (198)

Three commenters believe that the implementation plan must be considered with great care. (107, B17, 85). Miro M. Todorovich's (Scientists and Engineers for Secure Energy) comment is representative of the group's views:

> It is premature for NRC to adopt the particular guide, or even revised guides, at this time. Any guides promulgated should be tested in principle before being published. The use of safety goals and numerical benchmarks as tools for evaluation must be distinguished from attempts to cement them into regulations. The first application can be extremely beneficial; the second would spawn a continual regulatory and litigatory problem. Safety goals and guidelines

> should not be used explicitly other than in the regulatory process. Because the proposed draft does not specify how the guidelines should be employed, it may merely add to an already impossible regulatory load; guidelines would be of value only if they could subtract from the load by replacing existent regulations. (85)

Three commenters believe that the present state of PRA will make the implementation of the safety goals very difficult, if not impossible (B5, 49, 70). The following comment by Professor Gilbert Brown of University of Lowell is typical of this group:

> I'm afraid the safety goals won't be workable. This is especially true of the numerical guidelines. Without a yardstick, it would be impossible to measure how the given reactor measures up the proposed guidelines. Furthermore, given the state of the yardstick, it is not clear that we understand the physical phenomena that may occur in an accident well enough to even know what we are measuring. (B5)

Other comments include:

- Wait for the conclusion of the current source term investigation (109, 23)
- The implementation plan should provide a uniform approach to PRAs. (89, 96)
- Operators should be given flexibility to meet goals (L40)
- Numerical compliance is impossible, use consensus approach (32)
- How will plants just out of compliance be treated (72)
- Safety goals should be useful in design (57)
- Goals too vague to be practical (69)
- Narrow scope of goals to equipment reliability (140)
- Set trial period of one year (135)
- It is important to determine the effect that use of safety goals will have on regulatory efficiency (70)
- PRA should not be used to implement goals (12)
- Acceptable risk should be determined by a vote of citizens living near the plant (61)

- Make explicit the fact that the proposed risk levels are absolute, not balanced against other considerations (118)
- Include the risks of genetic defects (135)
- Explicitly acknowledge the limitations of quantitative methods (31)
- Use greatest risk individual instead of average individual (31)
- QA should be used to assure compliance (3)
- The implementation plan should emphasize reducing uncertainty in calculations (96)
- Explicitly include unquantifiable risks (96)
- Include in all results uncertainty (96)
- The implementation plan should distinguish between old and new plants (96)

3. QUALITATIVE GOAL ON INDIVIDUAL RISK

The proposed qualitative goal on the individual risk is stated as follows: "Individual members of the public should be provided a level of protection from the consequences of nuclear power plant accidents such that no individual bears a significant additional risk to life and health."

Eleven commenters agreed with the goal as proposed. (101, 69, 117, 58, 68, 54, 139, 93, 142, 34, 129). The following comment by Detroit Edison is representative of the group's views:

> Edison agrees that an appropriate and reasonable safety goal should include protection of individuals living near nuclear power plants. (101)

A number of commenters proposed restatements of the goal. Six commenters thought that the first and second qualitative goals should be combined or comparing nuclear risks against the risks of other activities should be included in the individual goal. The comment of the Department of Energy provides an example of these restatements:

> Individual members of the public should be provided with a level of protection from the consequences of nuclear powerplant accidents such that they do not bear a significant additional risk to life and health compared to other potentially severe man-made risks. (92)

Three commenters' statements were intended to clarify the meaning of the goal. The Atomic Industrial Forum (116) suggested defining individual as "individual in the vicinity of the nuclear power plant." John C. Fanta of Harvard Law School (31) believes that the goal should "express the fact that not all of the total risks of nuclear power plant operations are addressed." Edith Chase of the League of Women Voters of Ohio (64) suggests that the goal state that there should be "no adverse effects, prompt or delayed, on the life or health of the individual."

Seven commenters stated that NRC's goal should be that there be no risk of a serious accident or risk to an individual. (12, A11, A18, C29 +102, 27, 111, L13). The comments of Witan Consultants, Inc., and Robert L. Anthony of Friends of the Earth in the Delaware Valley summarize the views of this group:

> Expand the qualitative goals to include the intent of the NRC that no public deaths occur that are attributable to nuclear plant accidents. (12)
>
> We do not consider any risk of death from a nuclear plant acceptable! No individual should bear any additional risk; we do not know what "significant" means and do not accept it. (27)

Four commenters thought that the goal needed to be better defined to be implemented. (C30, 61, 91, 133). The comment of Deborah L. Norton of Action for a Non-Nuclear Future was typical of this group: "The word significant makes this goal vague and unenforceable."

Two commenters believe that only involuntary risks should be compared (C4, L7). The following comment by Joanna Hoelscher of Citizens for a Better Environment is representative of this viewpoint:

> CBE believes that it is inappropriate to compare voluntary with involuntary risks, i.e., the risks of nuclear power with other accident risks such as "driving, swimming, and flying." There is an element of personal choice in each of the latter which simply does not exist in the process which leads to the construction of a nuclear power plant. I can decide if I want to drive, or swim, or fly; but the selection of fuel and even the more basic decision about whether or not to even build a new electric generating plant are, by and large, out of my control. (C4)

Mary Basch (L13) thought the goal should "include the risks from routine emission, from the nuclear fuel cycle, from sabotage or from diversion of nuclear material."

Mark P. Oncavage of Floridans United for Safe Energy (129) stated that the "other proposed goals hopelessly undermine the attainment of this goal. Thus all proposed guidelines should be reconstructed to enhance the attainment of the first safety goal."

4. QUALITATIVE GOAL ON SOCIETAL RISK

The proposed guideline is the following:

"Societal risks of life and health from nuclear power plant accidents should be as low as reasonably achievable and should be comparable to or less than the risks of generating electricity by viable competing technologies."

Nine commenters thought that comparing the risk of nuclear power with other viable electrical generating technologies was too narrow. (130, 120 +C10, 122, 114, 69, 45, 116, 23, 38): This group believes that the risk comparison should be made against all other technologies. The following comment by Portland General Electric is representative of this group's views

> The societal risk evaluation from a comparative standpoint should be weighed against other beneficial technologies, and not just against operation of competing electrical generating plants. (130)

Eight commenters believe that ALARA should be eliminated from this goal or is vague or meaningless. (92, 68, 54, C17, 27, 113, 52, 74). The comments of IEEE Power Engineering Society and Connie Kline summarize the views of this group:

> The "as low as reasonably achievable" concept creates an open-ended specification of safety sufficiency that defeats the objective of improved regulatory stability and predictability. (68)
>
> Stating that risks should be "as low as reasonably achievable (ALARA)" is meaningless. To whom is this standard reasonable--the populace near a nuclear power plant or the utility? (113)

Seven commenters thought that the risks of nuclear power should be compared with all energy alternatives including renewable technologies and conservation. (A14, A18, C4, C29 + 102, 27, 97, 64). Tom B. Younkers' comment is typical of this group:

> I realize the Commission's narrow scope of consideration, but the question which compares different methods of generating electricity according to some theoretical risk factor does not allow room for consideration of displacing that electricity altogether with insulation or efficiency. These are two methods that have a much broader base to risk assessment. (A4)

Five commenters believe that the relationship between ALARA and the cost/benefit guideline should be made explicit. (114, 116, 100, 110, 142). The comment of the Atomic Industrial Forum is representative of the views of this group:

> The policy statement also notes that the use of a cost-benefit test for safety improvements is implicit in the goal through the use of the phrase "as low as reasonably achievable." However, this interpretation is often not well understood in practice, and we would recommend explicitly recognizing the appropriateness of cost-benefit balancing in the statement of the qualitative goal. (116)

Five commenters agreed with the proposal to compare the risks of nuclear power with the risks of other viable electrical generation technologies. (92, 58, 54, 83, A5). The comment by Texas Utilities Generating Co. summarizes the views of this group:

> The goal that societal risks from nuclear power plants should be comparable to or less than the risks of generating electricity by viable competing technologies is a useful and appropriate safety goal. (54)

Five commenters believe that risk comparisons are not appropriate in a safety goal. (117, A16, 34, 36, 111) The following comment by the American Nuclear Society is an example of the reasoning behind this position:

> The final thought relates to the comparison of societal risk for viable competing technologies. Although such comparison provides useful insights and may be a decisive factor in decision making, we doubt that it properly belongs in the safety goal framework. Such comparison studies should be performed, and we have no doubt that nuclear power will come out favorably in them. But we recommend that favorable comparison be deleted as a safety goal for the following reasons. If comparison is to be made with competing technologies, the comparison must logically be made on total impact, i.e., in the nuclear plant case on the total fuel cycle. We do not recommend this approach, however, since it carries us too far afield, and, more importantly, we do not believe that comparison of competing technologies is necessarily relevant.

> Compared technologies could, in principle, all present risks far below acceptable values with comparative risks therefore not a decisive factor. A further criticism of this part of the second qualitative goal is that it may lead to all competing technologies (assuming they all in time establish safety goals) specifying they must present comparable or less risks than the others, thus leading to a racheting process. (117)

Five commenters suggested that a risk comparison should include the risks from the total nuclear fuel cycle in order to place all risks on an equal basis. (31, A16, 38, 111, 52). The comment of John C. Fanta of Harvard Law School is representative of this group's views:

> The comparison made is not between the total risk of nuclear power plant operations and the total risks of competing technologies, but rather between only the risks of nuclear power plant accidents and the total risks of competing technologies. This second proposed goal should be amended to state that the total risks of competing technologies should be compared to the total risks of nuclear power. (31)

Three commenters thought that ALARA is an important part of the goal and should be emphasized. (101, 122, 117). The comment of Yankee Atomic Electric is typical of this group:

> The As-Low-As-Reasonably-Achievable (ALARA) standard is fundamental to an achievable safety goal. There is a limit on how much this country can afford to spend to reduce risk from all its technological activities. Current societal perspectives are causing more spending for light water rector safety. (122)

Other comments include:

- Unqualified agreement with proposed goal (58, 34).
- Supply and political risks to other energy sources such as oil should be considered (71).
- The risk comparison needs to be clarified (68).
- A societal risk goal is redundant to the individual risk goal (90).
- Remove "or less than" from goal (142).
- Include psychological stress in risk calculations (74).

5. NUMERICAL GUIDELINES ON MORTALITY RISKS

The proposed numerical guideline on mortality risks is as follows:

"The risk to an individual or to the population in the vicinity of a nuclear power plant site of prompt fatalities that might result from reactor accidents should not exceed one-tenth of one percent (0.1%) of the sum of prompt fatality risks resulting from other accidents to which members of the U.S. population are generally exposed."

Eight commenters believe that 1% is a more appropriate value than the proposed 0.1%. (B10, 117, 116, 58, 68, 128, 55, 142). The following comment by the Atomic Industrial Forum is representative of the views of this group:

> The proposed value of 0.1% of existing accident risk as a guideline for prompt fatality risk is excessively stringent and conflicts with the qualitative safety goals. This value should be increased to 1% or replaced with a formulation that effectively provides a more realistic and reasonable value for individual risk. (116)

Seven commenters thought that the guideline was too conservative. (112, 71, B10, 96, 62 +C21, 85, 126) The comment by Stone and Webster Corp. summarizes this group's views:

> The goals as defined by the NRC are too conservative. Even though these calculations of risk are mathematical exercises, they may end up in excessive costs for the generation of power. (B10)

Six commenters thought that the guideline was set too high. (2, 9 +141, 86, L13, 52, 61). The comment by Mary B. Davis of the Sorghum Alliance is typical of this group:

> The 0.1% yields too high a mortality risk, especially considering mortality risks of other aspects of nuclear industry (routine emissions, the nuclear fuel cycle, sabotage, and diversion of nuclear material, etc.) (52)

Five commenters thought that the individual, prompt fatality limit would, but should not, dominate the other numerical risk limits. (120+C10, 122, 114, 69, 38). The following comment by the Yankee Atomic Electric provides an example of this viewpoint:

> The NRC's proposed goals separated individual risk/prompt fatalities from population risk/latent fatalities, but established a common numerical guideline of 0.1% for the acceptable risk increment for either category. Thus, individual prompt fatality risk considerations will predominate in most scenarios. We believe the prompt fatality risk-goal of 0.1% of accidental deaths normally occurring may be too low. It translates roughly into a risk-goal of $5(10)^{-7}$ per year. Compared to the average mortality risk for accidents [$5(10)^{-4}$ per year] or for cancer [$2(10)^{-3}$ per year], it is extremely small. A more reasonable value must be chosen. (122)

Five commenters suggested extending the distance criteria from 1 to 10 miles. (45, 96, 117, 133, 24). The comment by Pennsylvania Power and Light Co. summarizes the views of this group:

> The risk of early (prompt) fatalities that might result from a nuclear power plant accident should be based on the population that can potentially receive life threatening doses. The NRC has stated that such exposure should not occur beyond 10 miles from the plant site. This led to the development of the 10-mile plume exposure emergency planning zone (EPZ). (45)

Four commenters thought that the NRC should set a value for prompt risk from nuclear power plants. (101, 135, 118, 64) Two suggested a value of 10^{-6} fatalities per year (118, 64). The comment by General Atomic Co. is representative of this group:

> The proposed numerical guidelines specify an incremental risk (0.1%) but do not identify within the guideline the total risk. These are specified in later sections of NUREG-0880. Since members of the general public may not read all of NUREG-0880, it is recommended that the numerical guidelines incorporate the total risk due to nuclear power plant accidents as well as the incremental risk. On pages 22 and 23 of NUREG-0880, these are no more than 5 in 10,000,000 per year for prompt fatality and 19 in 10,000,000 per year for delayed mortality. It is better to know one's total risk rather than an increment of an unknown base. (135)

Four commenters thought that nuclear risks cannot and should not be compared with other risks. (A8, 27, 113, 84) The following comment by Mrs. H. T. Reed of the Sierra Club of North Carolina summarizes the views of this group:

> Total risks from all causes are not comparable to the risk of meltdown effects. Personal risks are a matter of individual choice and action, such as taking refuge from lightning or going over the Niagara in a barrel, driving fast or slow, or not driving at all. Risk in other technologies is limited in area and self-limiting in time. To the extent that it increases in the age of chemistry, we should be trying to reduce other risks, not enlarge them by allowing given percentages for them. So that as social risks increase, then the risk of nuclear death becomes increasing wide and acceptable. (A8)

Three commenters thought that it was not wise to include both individual and societal risk in the same numerical guideline (130, 69, 92). The comment by Virginia Electric and Power Co. provides an example of the reasoning behind this position:

> The quantitative goals lump the risk to individual and population together for comparison where the qualitative goals address them separately. It is not credible that the individual risk and population risk will even be the same order of magnitude for many reasons, not the least of which are individual age and location with respect to reactor. (69)

Three commenters thought that the guidelines were confusing and its implementation plan unclear. (34, 111, 116) The comment by Robert English is representative of this group's views:

> The discussion is mixed up, is confusing and, therefore, does not provide unambiguous guidance for future decisions. (34)

Three commenters believe that the prompt fatality risks of nuclear power should be compared with the risks of other competing electrical generating technologies. (127, 126, 62 + C21). The following comment by Florida Power and Light Co. summarizes the views of this group:

> The quantitative risk guidelines and cost-benefit guideline appear inconsistent with the qualitative guideline requiring that the "total risks of nuclear power plants resulting from normal operation and

accidents are comparable to or less than the total risks of the operation of competing electricity generating plants." The individual total accident risk guideline, which applies to the most exposed individual is about 2.5 x 10^{-6}. Others in the vicinity of the plant would be exposed to a much lower risk. A coal plant, the competing form of generating electricity, would routinely expose large numbers of individuals to a risk of about 2 x 10^{-4}. These figures would indicate that the nuclear plant guideline is excessively restrictive. (126)

Other comments include:

- consider involuntary risks only (34, 64)
- support AIF proposal of individual risk 10^{-5} per year and societal 1 fatality per 1000 MWe per year (122, 114)
- disagree with use of biologically average individual (34, 86)
- delete societal risk limits
- distinction between prompt and delayed fatalities is unnecessary (89, 34)
- delete distance criteria (34, L13)
- compare with total mortality, not just accidents and cancer (38)
- guideline does not address what is reasonably achievable (38)
- actual experience shows that guidelines would relax safety, why change? (A10)
- guideline should not include multiple reactor site restrictions (120 +C10)
- agrees with prompt vs delayed distinction (112)
- use per MWe instead of per plant (112)
- define source term levels (69)
- apply guideline only to population exposed to risk (45)
- guideline should compare nuclear risks with the risks of other low probability events. (92)
- agrees with the use of biologically average individual (92)
- unqualified approval of proposed guideine (54)

- one mile criteria unclear (128)
- it is not prudent to use numerical guidelines (31)
- do not increase risk limit by increasing distance criteria (96)
- if all dangerous industries adopted this guideline, public risk would increase substantially (49)
- to concentrate on individual risk makes large societal risk appear acceptable (49)
- state range of total deaths from all nuclear risks (49)
- there is disagreement within the UK about whether safety guidelines should connect probabilities of releases with their consequences. (57)
- use only national fatality statistics (142)
- .1% nuclear risk limit when compared with numerous hazards could lead to nuclear being the largest hazard (124)
- estimating risk is not possible (124)
- guideline should include consideration of organ doses (67)
- guideline should consider injury risks of evacuation (67)
- distance criteria is too small (86)
- it is not possible to control risk this precisely (L36)
- risks of nuclear power should be compared with those of other energy alternatives (64)

6. NUMERICAL GUIDELINES ON CANCER RISKS

The proposed numerical guideline on cancer risks is as follows: "The risk to an individual or to the population in the area near a nuclear power plant site of cancer fatalities that might result from reactor accidents should not exceed one-tenth of one percent (0.1%) of the sum of cancer fatality risks resulting from all other causes."

Six commenters believe that 1% would be more appropriate than the proposed 0.1% (112, 45, 117, 68, 100 +131, 110). The following comment by Pennsylvania Power and Light Co. summarizes the views of this group:

> We believe the numerical guidelines have been developed too conservatively. We recommend that they be revised to reflect that risks from nuclear power plant accidents should be comparable to the risks from other technologies. Specifically, we recommend that the risk to an individual or the local population should not exceed one percent (1%) of the sum of other risks from technologies in the U.S. The 1% ratio is not too conservative and does assure an insignificant impact from nuclear power. Since the NRC intends to introduce the guidelines on a trial basis, the 1% ratio could be used and modified if determined to be unacceptable. If a 0.1% ratio is used, we believe it is highly unlikely to be increased even if operating history provides suitable justification. (45)

Five commenters believe that it is not possible to determine whether a cancer resulted from the operation of nuclear power plants. (65, 59, 50, 52, 63). The comment of Chester Maliszewski is representative of this group's views:

> I don't see how you come up with your projected numbers for the cancer rate associated with nuclear power plants. You are implying a level of knowledge that is not present in the technology you're using. Causation of cancer has not been sufficiently pin-pointed to allow you to claim much accuracy for your projections. (65)

Four commenters felt that this level of risk is unacceptable. (27, A1, A8, 65) The comment by Robert L. Anthony of the Friends of the Earth in the Delaware Valley is typical of this group's position:

> No risk of cancer fatality from nuclear should be added to other causes; neither are acceptable. (27)

Three commenters thought that the 50-mile radius defining the population at risk should be flexible depending on site-specific conditions. (120 + C10, 128, 57). Commonwealth Edison's comment is representative of the views of this group:

> The numerical guidelines have set forth a 50-mile radius for defining the population at risk. We suggest that this may be overly conservative in many cases. A better approach would be to let the individual plant assessments establish the radius of significant risk considering the site specific and area specific factors of interest. In addition to being more realistic, such an approach might avoid some basic philosophical (and possibly legal) difficulties if two sites, owned by two utilities, in two states, exist less than 100 miles apart. (120 + C10)

Three commenters thought that the NRC should determine a value for non-nuclear risks or set an arbitrary value for nuclear risks. (C10 + 120, 126, 118). The following comment by Professor Richard Wilson of Harvard University provides an example of this position:

> I would personally prefer that NRC explicitly state a risk level of 1 in 10^{-6} as the accepted risk level, and not 0.1% of a cancer rate. This is because 1 in 10^{-6} has already been widely discussed. Yet the numbers are not dissimilar. The cancer risk is about 2×10^{-3}/year and 0.1% of this is 2×10^{-6} per year. I have, therefore, no great quarrel with 0.1% of cancer rate provided it is agreed to as a de minimis risk to be acceptable without argument. (118)

Three commenters believe that the 0.1% value is too small. (121, 114, 126). The comment by Middle South Services, Inc. summarized the views of this group:

> There is also no logical basis for selecting 0.1%, nor is one cited anywhere in the document. This number could just as well have been 0.1%, 1%, or even 5% and would have still met the qualitative goals. Our society willingly accepts much higher percentages from other technologies. Why should nuclear power be afforded such special treatment? (114)

Other comments include:

- include risk of genetic defects (L13, 52)
- 0.1% should be tied to existing cancer rates not to the current cancer rate (101, 64)
- meeting the individual guideline ensures compliance with the societal goal (96, 57)
- unqualified agreement with guideline as proposed (83)
- guideline ignores cumulative risk of those living within 50 miles of two different plant sites (49)
- guideline cast solely in terms of "expected value,"
- supplement with "limit lines" and/or "CCDF." (120 + C10)
- this guideline will be difficult to implement. (69)
- instead of 0.1% of cancer mortality, compare with cancer risk of other technologies (92)
- consider only societal risk (116)
- consider only individual risk (58)
- divide guidelines in terms of individual and societal risk instead of in terms of prompt and delayed fatalities. (100 + 131)
- consider environmental effects (26)
- explicitly state that the risk to the population within 50 miles envelopes the total population. (70)
- use a 1000 person-rem limit (47)
- inconsistent with goal to compare with risks of competing technologies (137)
- individual and societal risk should not have the same value (57)
- use of PRA is not acceptable. (C4)
- it is not possible to annualize delayed cancer fatalities (24)
- NRC's cancer mortality model is not conservative (111)

- does not believe in concept of "acceptable deaths" (103)
- no rational for 13,000 deaths (59)
- contamination of food and water not considered (67)
- consider synegistic effects of radiation and pollution (86)
- use 100 mrem limit (L7)

7. BENEFIT-COST GUIDELINE

The proposed benefit-cost guideline is as follows:

"The benefit of an incremental reduction of risk below the numerical guidelines for societal mortality risks should be compared with the associated costs on the basis of $1,000 per man-rem averted."

Sixteen commenters thought that the guideline needs to be better defined or there must be a clear implementation plan in order for them to tell whether the $1,000 per man-rem averted is reasonable. Many wanted the NRC to explain the rational for choosing $1,000. (127, 130, 120+C10, 121, 69, 94, 2, 12, C1, 113, 103, 65, 59, 50, 91, 64). The following comment by Virginia Electric and Power Co. is typical of this group:

> The cost/benefit guideline is linked to the quantitative guidelines already discussed as too vague to be of practical value. Determination of the man-rems averted is subject to the same variables as population risk and with the cost of determining the value achieved added to the cost, $1000 may well be inappropriate. (69)

Fourteen commenters suggested that $100 be used instead of $1000. (122, 112, 100, 117, 116, 128, 137, 110, 136, 139, 142, C21, 4, 126). The Westinghouse comment provides an example of the reasoning behind this position:

> With these other guidelines already satisfied, efficient allocation of resources should result in the dollar expenditures to avert exposure consistent with those expended to save lives or reduce health risks in other activities and technologies. As pointed out in the 1981 AIF White Paper, a figure of $100/man-rem (equivalent to about $1 million/life using the linear relation between dose and cancer) would be more consistent with other activities. (110)

Eleven commenters felt that the $1000 value was too large. (114, 112, B10, 116, 92, 70, 55, 57, 77, C26, 85). The following comment by Duke Power Co. is representative of this group's views:

> The cost-benefit criterion of $1000/man-rem seems somewhat high. Although that particular value has a precedent in nuclear applications, it was originally chosen as being "conservative." (112)

Eleven commenters believe that the cost/benefit guideline should be deleted. Five felt it should only be used as a tool (92, 68, 54, C4, 89) and six felt that no risk is acceptable (A18, 27, C17, 9 + 141, 123, 52). The Department of Energy's comment summarizes the views of the first group:

> We recommend that the benefit/cost guideline be deleted. The numerical guidelines of individual and societal mortality risks are sufficient for public protection. The proposed numerical benefit/cost guideline works against the objective of having clear predictable requirements. (92)

The comment of Dennis Hoffarth is representative of the views of the second group:

> The mere concept of using a mathematical calculation to compare dollars to human life deserves extreme caution. We can't afford this approach with nuclear plants. We must face the mistakes of the past and be willing to force shutdowns or major repairs regardless of costs if there is significant danger of a major nuclear accident. (A18)

Eight commenters believe that the $1000 value is too small. (A5, 38, 111, 103, 65, 59, 86, L13). The comment by Russ Lacewell is typical for this group:

> Your proposal to spend $1,000 dollars per man hour rem of exposure prevented puts no thought at all toward the effect of those rem exposures. Who pays for the cancer treatments, the loss of job time? How much is a life worth? I don't know, but it is a lot more than $1,000 a rem. (103)

Eight commenters believe that the guideline should be discounted to account for the time-value of money. (122, 2, 133, 96, 77, 34, 10, 129). The comment of Yankee Atomic Electric Co. is representative of the views of these groups:

> We believe the issue of discounting should be somewhere addressed in the Safety Goals. Discounting addresses how future costs and benefits are discounted to present worth for decision-making. What is a reasonable difference in value for averting a prompt fatality now versus a cancer fatality twenty years later? It may be argued that by investing money not spent today to reduce present risk, a large

> increase in resources would be available in the future to achieve life saving then. (122)

Four commenters thought that plant damage losses should be excluded from the cost/benefit calculation (122, 114, 58, 128). The following comment by Bechtel Power Corp., summarizes the views of this group:

> The factors to be included in this evaluation must be clearly defined. Factors which have large economic impact to the utility with little or no risk to the public should not be considered as part of the NRC's regulatory charter nor part of the safety goals. Therefore, reduced risk of economic loss of the plant itself should not be included in these evaluations. (128)

Three commenters believe that only the direct costs of an improvement and direct safety benefits should be considered in the cost/benefit calculation. (117, 116, 100). The comment of the Atomic Industrial Forum provides the reasoning behind this position:

> In implementing this guideline, consideration of benefits should be limited to public risk reduction and consideration of costs should be limited to the immediate costs of proposed safety improvements. Economic factors relating to potential future plant or offsite property damage are not related to safety and thus, are inappropriate for inclusion in this benefit-cost balancing process. (116)

Other comments include:

- unqualified support for the proposed guideline (101, [illegible] 118)
- liability loss or offsite economic damage should be excluded (112, 114)
- benefit cost guideline is not consistent with <u>de minimus</u> prompt and delayed risk guidelines (57, A13)
- use of 50 mile limit is not practical (96, 10)
- people living near the plant should be compensated for extra risk they assume (133, 24)
- NRC should state a value for man-rem equivalent for statistical death. (C16, 34)
- include economic losses in cost/benefit calculation (96, 34)
- do not annualize (A8, 124)

- include the cost of replacement power (58)
- consider all sources of exposure (67)
- use variable value depending on the size of man-rem reduction (68)
- consider total population (34)
- use 50 miles cut off (135)
- there are site specific problems with attempting to implement 50 mile limit (109)
- use of cost/benefit analysis should be limited to a few cases (110)
- instead of $1000 per man-rem averted criteria use relative contribution to core melt probability (10)
- this guideline would eliminate spending money to reduce uncertainty which sometimes is more valuable than reducing risk (70)
- suggests $1000 for large accidents and $100-200 for small releases (23)
- suggests that NRC use cut off value of 500 mrems in calculating health risks (55)
- use guideline in designing new plants (96)
- use guideline in reviewing NRC requirements (139)

8. PLANT PERFORMANCE GUIDELINE - LARGE SCALE CORE MELT

The numerical guideline for the plant performance is as follows:

"The likelihood of a nuclear reactor accident that results in a large-scale core melt should normally be less than one in 10,000 per year of reactor operation."

Fourteen individuals and public interest group commenters believe that the risk of one in ten thousand of a large-scale core melt per year of reactor operation is too high. (A1, A20, A22, 34, 27, 113, 111, 97, 54, 65, 52, 61, 63, 64). The following comment by Lavinia B. George is representative of the views of this group:

> The proposed goals that the risks of a core-melt at one reactor during one year of operation should be one in 10,000 calculates to a 45 percent chance of melt in a 200 reactor industry over a 30-year operating cycle. Certainly, this is too great a risk. (A1)

Nine utility, vendor and nuclear industry group commenters agreed with the characterization of this guideline in NUREG-0880 as subordinate to the other numerical guidelines; that it provided an interim limitation to be used by the staff in reviewing PRAs; and that it should not be a requirement. (120, 114, 112, 58, 54, 110, 128, 142). The comment by Commonwealth Edison summarizes this group's views:

> Although we are in agreement with this guideline, it is important that the policy statement emphasize that this large scale core melt goal is secondary to the goals on individual and societal risk, as well as, the benefit-cost ratio; and is not to be considered a requirement. Furthermore, we believe that core melt frequency is a good indicator of the financial risk to a utility from an accident which causes core damage, even though the scenarios which contribute most to core melt frequency are not necessarily the major contributors to plant risk. (120)

Eight commenters thought that the plant performance guideline was incomplete because it failed to relate accident risks, through containment reliability and radioactive releases, to the consequences of core melts to the public. Some felt that the plant performance guideline could and should be derived from the guidelines on prompt and delayed mortality risks. (69, 118, 90, 96, 109, 72 + C12, 38, 67). The following comment by Sherwood Davis is an example of this position:

> This plant performance guideline does not relate to offsite releases but to probabilities of a core melt and releases within containment. It would be more meaningful in light of the proposed prompt and delayed mortality risk guidelines to relate the probability and source term of an environmental release following a large-scale core melt accident. (67)

Four commenters thought that, in light of the other three numerical guidelines, the plant performance guideline was redundant and unnecessary. (127, 122, 116, 68). The comment by Alabama Power Co. reflects the views of this group:

> The proposed guideline on the likelihood of a large-scale core melt does not appear necessary. Since the dominant contributor to risk from a nuclear power plant accident is a large-scale core melt, the individual and societal mortality risks are dominated by this type of accident. Therefore, the guideline on mortality risk adequately addresses the concern about core melt accidents. Alabama Power Company opposes the numerical guideline for plant performance since it is redundant and unnecessary. (127)

Three commenters suggested using this guideline as a screening criteria. If utilities could prove compliance with this guideline, it would not be required to prove compliance with other numerical guidelines. (114, 98, 142). The following comment by Middle South Services, Inc. is representative of this group's views:

> Its use should be as a screening criterion - i.e., if one passes this test, it should not be necessary to check to see if the individual and societal criteria are met. (114)

Three commenters thought that the guideline was not practical because of the difficulties of performing and using PRAs. (49, 124, 129). The comment of Thomas and Hair (co-counsel for Limerick Ecology Action, Inc.) summarizes the views of this group:

> The plant performance guideline rests implicitly upon a purported ability to reliably make such absolute probability calculations, and this ability has <u>not</u> been demonstrated to exist. (49)

Other comments include:

- unqualified agreement with guideline as proposed (139, 101)
- proper implementation is essential to the usefulness of this guideline (100,104)
- The guideline should emphasize operational/basic engineering aspects of plant performance (92, 89)
- no basis given for 1/10,000 guideline (103, L8)
- the guideline essentially relates to economic aspects of nuclear power: NRC should consider economic aspects (23); NRC should not consider economic aspects (55)
- guideline is too restrictive (137)
- guideline should include external initiators and be more stringent (57)

9. QUESTION 1 - ECONOMIC LOSS

At the end of the proposed policy statement, the following background material and question are pressented:

> "The proposed benefit-cost guideline provided in furtherance of the as low as reasonably achievable (ALARA) principle would set a numerical formula of $1000 per man-rem averted for consideration in tradeoffs of societal mortality risk reductions against the cost of achieving them. The discussion paper describes the basis of the trade-off calculations as follows: 'The benefit of an incremental reduction of risk below the numerical guidelines for societal mortality risks should be calculated for the population reasonably expected to be within 50 miles of the nuclear power plant site. The associated costs should include all reasonably quantifiable costs (e.g., design and construction of plant modifications, incremental cost of replacement power during mandated or extended outages, changes in operating procedures and manpower requirements).'
>
> Question 1: Should the benefit side of the tradeoffs include, in addition to the mortality risk reduction benefits, the economic benefit of reducing the risk of economic loss due to plant damage and contamination outside the plant?"

Ten commenters were in favor of including the aversion of economic loss as a benefit in the benefit-cost guideline (24, 45, 57, 58, 96, 111, 115, 124, 132, 133). EPRI calculated the expected annual off-site property risk to range from $199 to $14,800 (1974 dollars). Pennsylvania Power and Light calculated a range of $1 million to $10 million per reactor year. The following comment of J. M. Griesmeyer (ACRS staff) is an example of the reasoning behind this position.

> Economic loss due to plant damage and contamination outside of plant would be as real a loss to society as direct health effects and may result in indirect health effects that are as large as direct effects. Many available risk studies suggest that the off-site economic costs of accidents would be larger than health effects cost at the nominal $1000/man-rem suggested in the proposal. Furthermore, some economic effects are omitted in the risk studies and others such as decontamination costs seem to be underestimated. Societal resources used to clean up and cope with a large release of radio-

> active material are not available to improve national productivity and general health care, or to reduce other specific societal risks for which relatively modest expenditures, compared to $1000/man-rem, are likely to defer a premature death.
>
> Experience and logic tell us that both offsite and onsite economic losses will usually be born by society, ultimately if not initially. Hence, the reduction in such losses should be considered as a benefit of an improvement to be balanced against its cost. (96)

Twenty-four commenters were opposed to inclusion of the economic benefit of reducing the risk of economic loss. The following comment by Duke Power Company summarizes the views of this group (23, 55, 68, 69, 90, 92, 98, 100, 101, 104, 110, 112, 114, 116, 117, 120 & C10, 122, 126, 127, 130, 136, 139, 142, C16):

> The benefit side of the benefit-cost analysis should represent a measure of the potential reduction in risk only in terms of public health and safety. The NRC is not charged with, and should not concern itself with, protecting the financial investment of a utility and its shareholders in a nuclear plant. Likewise, neither the economic benefits of electricity produced by nuclear power plants, nor the potential economic losses associated with their operation come within the purview of the NRC. As a practical matter, the calculation of economic consequences of reactor accidents is much more difficult and subject to larger uncertainties than the evaluation of radiological consequences, and would thereafter unduly complicate the cost-benefit analyses. (112)

10. QUESTION 2 - CONTAINMENT AVAILABILITY

At the end of the proposed policy statement, the following background material and question are presented:

> "The primary numerical guidelines address the permissible net residual health risks after application of all elements of a defense-in-depth safety philosophy. Safety against core melt and integrity of containment are two of the chief elements of that defense in depth. A further guideline sets a proposed numerical limit on core-melt probability. However, for reasons stated in the paper (NUREG-0880), no numerical guideline for containment failure risk is included. Instead, qualitative guidance and the operation of the other numerical guidelines are relied on to guide regulation of containment effectiveness.
>
> "Question 2: Should there be added a numerical guideline on availability of containment function, given a large-scale core melt?"

Four commenters (24, 69, 101, 147) felt that a numerical guideline on the availability of containment function should be added to the safety goals. The view of Virginia Electric and Power Company (69) follows:

> The final analysis of the safety goal will compare the plant capacity to contain harmful radiation against guidelines of what maximum amount might be released without regard to type of accident. Any guidelines must therefore include a measure of containment effectiveness under worst case, i.e. core melt conditions.
>
> VEPCO feels that the guidelines call for evaluation of the entire plant as a system to keep radiation from the public and, therefore, a numerical analysis of containment should be part of the guideline.

Twenty-six commenters were opposed to a numerical guideline on containment availability. (23, 45, 55, 57, 58, 68, 81, 92, 98, 100, 104, 110, 112, 114, 115, 116, 117, 120 & C10, 122, 126, 127, 129, 133, 136, 139, 142). The following comment by the Atomic Industrial Forum (116) is representative of the group's views:

> The individual and societal mortality risk guidelines inherently serve the objective of ensuring low probability of large release accidents. The addition of a containment guideline to the proposed set of guidelines would overspecify the framework and complicate implementation and could lead to imposition of requirements that conflict with the benefit-cost guidelines.

Three commenters (A1, 111, 124) were not responsive to the question.

11. QUESTION 3a - UNCERTAINTY

At the end of the proposed policy statement, the following background and question are presented:

> "The last paragraph of the proposed policy statement calls on the NRC staff to develop, for Commission review, an action plan for implementation of the goals and numerical guidelines. The policy statement as well as the discussion paper (NUREG-0880) provide guidance on the implementation approach to be employed, but only in rather general terms. Comments and suggestions are solicited for consideration in development of a detailed approach to implementing the safety policy. Responses to the following specific questions would be welcome.
>
> "Question 3a: What further guidance, if any, should be given for decisions under uncertainty?"

Four commenters (45, 104, 120, 139) recommended that very little or no guidance should be provided for treating uncertainties.

Nine commenters (23, 68, 77, 92, 98, 110, 117, 126, 133) stated that the NRC should prescribe how to perform PRA calculations and then the impact of the uncertainties would be minimized. A typical comment by the Department of Energy (92) was:

> We view the entire process of using quantitative guidelines that require probability risk calculations to be a process that applies to decisions made under uncertainty. We think the correct approach is to specify the decision rules that require PRA calculations including specification of uncertainties and to reach agreement on the way the PRA calculations are to be done.

Eight commenters (57, 58, 100, 112, 114, 116, 127, 142) stated that PRA results should be calculated using best estimate values and judgment should be relied upon if the PRA results, with uncertainties quantified, overlap the numerical guidelines. The Atomic Industrial Forum (116) provided a representative comment for this group:

> In using quantitative risk assessment methodology and safety goals in regulatory decision-making, it is important to use best estimate values of risk and to estimate the range of uncertainty in any risk estimate. The weight given any quantitative risk estimate must be dependent on its relationship to the appropriate numerical guideline being used in the decision process. In many cases, the estimated risk value, even with uncertainty, may fall well above or below the relevant numerical guideline. In such cases, regulatory decisions may be based on the PRA studies and numerical guidelines with greater confidence. However, where the best estimate results of PRA studies are near the numerical guideline value, additional sound engineering judgment must support the regulatory decision process.

Other comments (69, 90, 111, 115) were not responsive to the question.

12. QUESTION 3b - CONFLICTS

As part of Question 3, the following was asked:

> "Question 3b. What further guidance, if any, should be given on resolution of possible conflicts among quantitative aspects of some issue?"

Seven commenters (68, 100, 101, 104, 110, 117, 139) apparently did not understand the question because their comments were not responsive. Three commenters (69, 112, 115) stated that further guidance is not needed and two commenters stated that no conflicts are expected (98, 127). Some of these commenters, such as the following comment by Duke Power Co. (112), recommended a trial period of use:

> Further guidance is probably not advisable until the guidelines have been subjected to a trial period of use, after which problems in applying them can be more readily resolved.

Three commenters (45, 92, 142) recommended that further guidance be given to resolve conflicts and a fourth commenter Florida Power & Light Co. (126) suggested some guidance:

> Engineering judgment cannot be eliminated through implementation of PRA techniques. Guidance to the staff will be required to handle a situation where a safety goal quantitative guideline is not met, but is within the bounds of uncertainty (say < 10), and all backfits to bring the plant into compliance are not cost-beneficial. For situations of this type it would seem that:
>
> - an evaluation of the conservatism in the PRA methodology may be sufficient to allay any undue risk concern generated by the PRA, or
>
> - additional inspection, or test or surveillance requirements may be appropriate in lieu of a backfit that is not cost-beneficial.

Three commenters (58, 114, 116) proposed changing the individual numerical risk guideline to resolve possible conflicts. The following comment by the Atomic Industrial Forum (116) is representative of this group:

The best way to avoid possible conflicts among quantitative aspects of an issue is to ensure that the goals or numerical guidelines to be used in the decision-making process are well balanced; that is, no one consideration relating to individual risk, societal risk, benefit-cost or large scale core melt should dominate all decisions to the extent that the other factors become meaningless. Our comments on the proposed numerical guidelines of 0.1% on prompt fatality risk reflect our concern on the need to avoid such conflicts. The prompt fatality guideline, as proposed, would tend to dominate resolution of many issues in a manner which would conflict with benefit-cost considerations in that changes to design or operating procedure may be required which are far more costly than $100 or even $1,000/man-rem.

13. QUESTION 3c - ACCIDENT INITIATORS

As part of Question 3, the following was asked:

> Question 3c: "What approach should be used with respect to accident initiators which are difficult to quantify, such as seismic events, sabotage, multiple human errors, and design errors?"

Six commenters (98, 101, 126, 127, 130, 142) recommended that the staff continue to use a deterministic approach for initiators which are difficult to quantify. Portland General Electric (130) provided a representative comment:

> In dealing with those accident initiators that are difficult to quantify, such as seismic events, the methodology at the present must follow the currently-used deterministic approach. It is possible to include such events in risk assessments. However, they primarily contribute to calculational uncertainties. It may be that in the future advanced risk assessment methods may be developed that are capable of dealing with these uncertainties, but not at the present time.

Thirteen commenters (23, 58, 68, 92, 100, 104, 110, 112, 114, 116, 117, 120 & C10, 139) recommended a dual-pronged approach. They felt that most of the accident initiators could be quantified for a probabilistic analysis; however, sabotage should be handled deterministically. The following comment by the Electric Power Research Institute (58) is representative of this group:

> We do not believe that the NUREG-0880 report need provide additional guidance on the quantification of seismic events, multiple human errors, and design errors. A comprehensive and well-executed probabilistic risk assessment should address these issues, and guidance is being provided in the pending PRA Procedures Guide, NUREG/CR-2300. In our opinion, the risk from sabotage cannot be meaningfully quantified and should be excluded from probabilistic risk assessments and safety goals. We believe that the existing engineered safety features and the required security measures limit this risk to a small fraction of the quantified accidental risk, but we know of no analytical procedure which can demonstrate this.

Five commenters (45, 57, 69, 90, 115) proposed alternative approaches:

- Recognize that such events have a different level of realism and evaluate using a set of goals for conservative analysis (45)

- Four examples should be dealt with in different ways: multiple human errors by improved operator training, improved display of relevant information, etc.; design errors by properly organized system of cross-checks and review; seismic events possibly by application of the 0.1% increase in casualty rate; sabotage - no comment at this stage (57)

- Address according to order of magnitude of risk and state of the art of relevant technology (69)

- Seismic events and sabotage - "use of general terms"; human errors control by following U.S. Navy training system for operators; PRA would identify design errors (115)

- To account for uncertainties, plant design should include robust line of defense, e.g., design to withstand much larger accelerations that the design acceleration; emphasis should be on robustness and mitigation procedures (90)

14. QUESTION 3d - MEAN, MEDIAN, CONFIDENCE

As part of Question 3, the following was asked:

> Question 3d: Should there be definition of the numerical guidelines in terms of median, mean, 90 percent confidence, etc.? If so, what should be the terms?

Eleven commenters (23, 57, 58, 70, 100, 104, 110, 112, 116, 117, 130) advocated use of best-estimate calculations. Nine commenters (45, 58, 68, 100, 110, 112, 114, 126, 130) recommended the use of mean values as stated in the following comment by Portland General Electric (130):

> Probabilistic risk assessment studies should be used to provide best-estimate probabilities and consequences. Mean values associated with calculated uncertainties are most appropriate for such application. These specifications should be made in the finalized procedures guide.

Whereas three others (98, 104, 120 & C10) wanted to use median. The following comment by SNUPPS (104) is representative:

> The numerical guidelines should be based on best estimate, i.e., median calculations. When many factors are combined it is not always apparent which assumptions are 'conservative' and which are 'non-conservative.'

Six commenters (90, 92, 115, 133, 139, 142) advocated further specification of the numerical guidelines and three commenters (69, 101, 127) opposed it at this time.

15. QUESTION 3e - METHODOLOGY

As part of Question 3, the following was asked:

> "Question 3e. Should the staff action plan include further specification of a process which will lend credibility to the use of quantitative guidelines and methodology? If so, what should be the principal bases and elements of such guidance?"

Four commenters (58, 127, 139, 142) stated that no further specification should be provided at this time. However, sixteen commenters (23, 45, 68, 69, 92, 98, 100, 101, 104, 110, 112, 114, 115, 116, 120 + C10, 126) were in favor of further specifications and seven of them recommended the PRA Procedures Guide (NUREG/CR-2300).

16. QUESTION 3f - APPLICATION TO INDIVIDUALS

As part of Question 3, the following was asked:

> "Question 3f. On what basis should the numerical guidelines be applied to protection of individuals? Should they be applied to the individual at greatest risk, or should they be used in terms of an average risk limit over a region near the plant? Any comments or suggestions pertaining to the present discussion of this topic (or other specifics) would be welcome."

Comments were about evenly divided between those who would apply the numerical guidelines to the individuals at average risk and those who would apply the guidelines to the individuals at greatest risk. However, most of the comments included caveats, such as assumptions of different guidelines or specific definitions of maximum risk. Some comments were ambiguous (45). The average risk comments included those who supported:

- average risk over region (98, 101, 120 + C10, 133) usually in reference to biologically average individual (100)
- average risk but limiting region to 1 mile from plant (110, 112, 92) or 2 miles (23), or at 1 mile using a directional average with realistic meteorological assumptions and referring to a 1% limit of prompt fatality risk (58)
- average risk, in view of belief that "proper" numerical guideline would assure adequate protection of individual at greatest risk (112)
- average risk, generic and mathematically derived, to a person exposed in "a defined area" (69)

Some of those supporting the average risk concept cautioned against assuming a maximum risk individual (23, 120 + C10); it was noted that even defining this individual would serve as a focus of dispute (122) and would put the utility (in a site-specific application) in the position of having to meet a standard that changed as individuals near plant moved to new locations (69). It was further noted that numerical guidelines for individual risk should be more "tolerant" (i.e., > 0.1%) because individuals are mobile and can take protective actions. (69)

Comments supporting the maximum individual risk concept noted that the guideline would apply to

- biologically average, maximum exposed individual (126, 127, 139)
- individual at greatest risk, assuming the level of the guideline takes this into account (57)
- maximum exposed individual which must be defined in prescriptive rules (68)
- maximum exposed individual based on best-estimate or average factors, not worst case (116)
- individual at midpoint of closest population segment in downwind sector (122)
- no selected population group but assuming guideline different from NRC's (114)
- group of individuals which as a whole have maximum exposure (142)

17. QUESTION 4 - RISK AVERSION

At the end of the proposed policy statement, the following background material and question are presented:

> "The Advisory Committee on Reactor Safeguards has proposed, as part of a safety-goal approach 'intended to serve as one focus for discussion,' that greater weight should be given to a single very severe accident than to a number of smaller accidents with the same total consequences. (NUREG-0739). The ACRS proposal includes a specific quantitative formula for reflecting such 'risk aversion.' The risk aversion concept and the ACRS formula were discussed in the NRC-sponsored safety-goal workshops, with controversial results. As pointed out in the discussion paper (NUREG-0880), some elements of the defense-in-depth approach (containment, remote siting, emergency plans) aim at mitigation of severe accidents. However, the proposed guidelines include no specific risk-aversion formula.
>
> "Question 4. Should there be specific provision for 'risk aversion'? If so, what quantitative or other specific provision should be made?"

Very few responses (57, 72, 118, 133, C-12) favored inclusion of a specific risk-aversion factor. Those who advised against such a factor cited the following reasons:

- The proposed guidelines are conservative and essentially take into account public aversion to multiple-fatality accidents. (23, 45, 98, 101, 120 + C10, 126)
- A risk-aversion factor would overemphasize high-consequence low-probability accidents and cause unwarranted attention to accidents that contribute little to overall plant risk. (100, 114, 116, 142)
- Because formulation of such a factor would require consideration of social perceptions which are not easily understood, are dynamic and dependent on unpredictable circumstances, involve many variables, etc., it is not practical nor objective to include it in the safety guidelines. (100, 122, 139, 142)

- Adopting a subjective criterion might further inflame issue of nuclear power plant safety and increase difficulty in obtaining public understanding. (116, 127)

- A preferred alternative would be to reference nuclear risk estimates against other multiple-fatality risks, as in WASH-1400. (58)

- Inclusion of risk-aversion factors unwarranted in light of very large uncertainties associated with low-probability, high-consequence accidents. (112)

- Effort to develop factor would involve inefficient use of resources. (58, 136)

- Steps taken to prevent and mitigate severe accidents provide for risk aversion. (69)

- Only a small minority of population, those who cannot accept the finite probability of a Class 9 accident, want a risk-aversion factor. (115)

- No need in principle, since as a matter of equity, isolated victims and victims of large accidents should be equally protected. (90)

Those who favored inclusion of a risk-aversion factor advanced the following reasons:

- Unless risk aversion is taken into account, the proposed safety goals will deviate significantly from popular values. (133)

- Some allowance for risk aversion should be made, the form to be discussed by experts (57); the ACRS proposal would be reasonable for trial use. (72, C12)

- Risk aversion could be taken into account by calculating the total societal impact in some conservative way, e.g., equivalent to the 95th percentile of risk distribution. (118)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

July 12, 1982

MEMORANDUM FOR: Chairman Palladino
Commissioner Gilinsky
Commissioner Ahearne
Commissioner Roberts
Commissioner Asselstine

FROM: Forrest J. Remick

SUBJECT: SAFETY GOALS FOR THE OPERATION OF NUCLEAR POWER PLANTS

OPE proposed a Commission meeting to discuss Safety Goals. The purpose of the meeting is to provide the Commission with an update of what has transpired since the publication of the Commission's Proposed Policy Statement on Safety Goals for Nuclear Power Plants in the Federal Register. Secondly, the purpose is to brief the Commission on recommended further development of the Commission Safety Goals, in the light of comments and the staff's implementation plan. Finally, this meeting will provide an opportunity for the Commission to discuss the proposed implementation plan with the staff.

In addition to obtaining preliminary Commission reaction to the proposed revised policy statement we would like to obtain Commission endorsement of a key principle of application for NRC use of safety goals; namely, that as the Commission said before in its policy statement--the Commission intends that the goals, benefit-cost guideline, and design objectives would be used by the NRC staff in conjunction with probabilistic risk assessments and would not substitute for NRC's reactor regulations in 10 CFR Chapter 1. Rather, individual licensing decisions would continue at present to be based principally on compliance with the Commission's regulations. A second key principle of application which we recommend that the Commission endorse is that regulatory decisions to use probabilistic risk assessment should be made on the basis of an appraisal of its value in the specific application. Thus, implementation of an NRC statement of safety policy should not, of itself, mandate the use of probabilistic risk assessment. This latter point was stated as a recommendation in the discussion paper contained in NUREG-0880 but was not contained in the Commission's proposed policy statement. We think a Commission statement of this type is desirable to make clear that it was not the Commission's intent to require the industry to perform additional probabilistic risk assessments simply because Safety Goals were endorsed.

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Copies of a proposed revision to the policy statement on Safety Goals is attached. Changes were made in the attached policy statement on Safety Goals to convert the draft statement to a final policy statement and to coordinate the Safety Goals statement with the staff's implementation plan. Further, changes were made as a result of comments received and recommendations from members of the staff. The reasons for the significant changes to the Safety Goal statement are provided in the following discussion.

1. Inclusion of routine emissions. The Commission policy statement has been revised to include the public risks from all radioactive releases from the operation of nuclear power plants. The risks of the nuclear fuel cycle and risks stemming from sabotage and diversion of nuclear material continue to be excluded. Previously, the focus of the policy statement in NUREG-0880 was on reactor accidents. However, in response to numerous public comments, we now propose to include the risks to the general public from releases due to normal operation. The proposed approach in the revised paper has been taken from the recent Clinton Final Environmental Impact Statement (NUREG-0854). The categories of releases are shown in the statement; this statement shows the staff's general conclusion that the sum of the accident risks are roughly comparable to the risks of routine emissions. The ACRS, in its letter of June 9, 1982, to the Commission, agreed with the exclusion (at this time) of the risks associated with the rest of the nuclear fuel cycle but did not comment specifically on the desirability of including the risks of routine emissions.

2. Energy comparison to competing technologies. Many commenters criticized the latter half of the second qualitative safety goal on societal risk--namely, that nuclear risks should be comparable to or less than the risks of generating electricity by viable competing technologies. NUREG-0880 suggested that viable competing technologies essentially came down to coal-fired generating plants and excluded those using hydro, oil, or gas. A number of commenters believed that technology described as viable is too narrow and such energy risk comparisons may carry the NRC "....too far afield," and that the comparisons are not necessarily relevant. Conceptually we believe that coal is the only viable alternative and that such risk comparisons are relevant, at least in theory, and would recommend that the Commission continue to endorse the concept. Therefore, we have retained the statement that nuclear risks are comparable to or less than the total risks of competing means of electricity generation. However, we recommend that the Commission delete the technology comparison portion of the Safety Goal because neither the staff implementation plan nor the rest of the Commission's policy statement implements the concept. The ACRS did not comment on the utility of energy comparisons, but did say that if the Commission chose to make such comparisons it should conclude that the policy statement either indicate the risks of the rest of the nuclear fuel cycle are small or that they will be addressed later.

3. Design objectives versus numerical guidelines for individual risks. We believe that the term "design objective" better describes the intended use of risk levels than the term "numerical guidelines". In addition to plant design and operation, we would include remote siting and emergency planning as integral parts of the defense-in-depth concept. Moreover, the term design objective is more descriptive of a goal or aiming point vis-a-vis a numerical guideline and, therefore, should make the point more clearly that these are not new regulatory requirements. This proposed change should improve the understanding of the Commission's policy statement and the NRC staff's implementation plan--but some additional conforming changes to remove reference to numerical guidelines will be necessary in the implementation plan. In its general comments on the safety goals, the ACRS recommended that the numerical guidelines be "design-oriented." We believe the adoption of the term "design objective" is consistent with this recommendation.

4. Average individual mortality risks. A number of commenters were confused over the definition of individual risk in the policy statement. There was confusion over which individual (i.e., average or most exposed) was being considered, the location of these individuals, and how to handle cases where there were no individuals within a mile of the site boundary. In response to these comments we clarify that the individual risk design objectives are to be based on the risk to an average individual--that is biologically and locationally average whereby the individual risks are to be averaged within an annular area of one mile width surrounding the nuclear power plant site boundary. This means that the average individual is found by accumulating the individual risks and dividing by the number of individuals residing in the vicinity of the plant. Also, we incorporate the staff recommendation that for those plants where no individual lives within the vicinity of the site, a hypothetical average individual be located one mile from the the site boundary for risk estimation purposes.

   The ACRS recommended that numerical guidelines on individual risk address the risk to individuals subject to largest risk of exposure. However, the ACRS suggested that, for operational convenience, the guidelines be expressed in terms of an assumed biologically and locationally average individual living within one mile from the site boundary if it can be assumed that there would not be significant variations in risk to such individuals over this region and that the risk would be less at distances greater than one mile."

5. Substitution of a design objective for individual cancer fatalities for the former individual and societal numerical guideline. The staff and several commenters point out that the individual risk guideline will predominate in most scenarios. The staff notes that control of the individual delayed as well as prompt mortality risk in the vicinity of the

plant limits the risk to the population living in the area of the plant. Thus, as previously stated by the Commission in its draft policy statement, if the guideline is met for individuals in the immediate vicinity of the plant site, the risk to persons farther away would be much lower than the limit set by the (old) societal guideline.

The ACRS recommended replacement of the societal risk guideline by "one that places a numerical limit on the statistical deaths per 1000 MWe reactor year (or some similar unit)." The ACRS also suggested the policy statement should point out the protection to society provided by the individual risk guidelines. We believe the revised draft is responsive to the latter ACRS comment.

6. Benefit-cost guideline. In response to a number of comments, we propose that the Commission consider the allowing the $1,000 per man-rem averted to be adjusted beyond 1983 in order to allow for general inflation in the future. Secondly, in order to conform to the staff's implementation plan which allows use of the benefit-cost principle both above and below the design objectives in certain situations, we propose deletion of the phrases which indicated the benefit-cost principle would only be applied below the (old) numerical guidelines. Lastly, we point out that the benefit-cost guideline is a societal risk reduction beyond the substantial societal protection already implicit in the individual risk design objectives. Therefore, we propose that the benefit-cost guideline would act as a surrogate for the old societal risk numerical guideline contained in Commission's draft policy statement. As a result, reference to population for both prompt and delayed risks were deleted. In addition, the rationale on societal risk was moved and amplified. The ACRS did not specifically comment on these features of the benefit-cost guideline.

7. Plant performance design objective. The focus of this design objective has been sharpened to provide a better description of the type of accident to be evaluated. We believe that the loss of core protective features leading to severe core damage better characterizes our meaning than large scale core melt. This change was proposed in the comment supplied by the Department of Energy. DOE believes that this type of statement provides a better focus on design and operational aspects under control of the operator and not on research and development associated with investigations of core melt and is consistent with the intent of the former guideline.

   The ACRS commented that "design-oriented" numerical guidelines may have to be more limited in scope and suggested that, for example, numerical specifications on the required reliability of core cooling may be appropriate. However, the ACRS did not propose a change in terminology to describe severe core damage.

8. Implementation. A key feature of the Commission's earlier policy statement, contained in NUREG-0880, has been retained. Namely, that the Commission intends that the goals, benefit-cost guideline, and design objectives would be used by the NRC staff in conjunction with probabilistic risk assessments and would not substitute for NRC's reactor regulations in 10 CFR Chapter 1. Rather, individual licensing decisions would continue at present to be based principally on compliance with the Commission's regulations. Also, the Commission believes that regulatory decisions to use probabilistic risk assessment should be made on the basis of an appraisal of its value in the specific application. Thus, implementation of the statement of safety policy should not, by itself, mandate the use of probabilistic risk assessment.

   A suggested trial period of 2 years is proposed as an acceptable period of time to evaluate the Safety Goals, benefit-cost guideline, design objectives, operating limits, and implementation plan. The last addition to the implementation section in the revised policy statement consists of a summary of key aspects of the staff's action plan for implementing the Safety Goals. We believe that the Commission should endorse, subject to revision as necessary, the staff action plan for use during the trial period.

   The ACRS said that when the implementation plan is available for review, it will provide further comments to the Commission.

9. Response to Commission questions:

   a. Economic loss.

      At issue here is whether the Commission should consider aversion of economic loss to be a benefit in the application of a benefit-cost concept to safety decision-making. We note that the NRC staff and the ACRS favor inclusion of other averted losses essentially in order to obtain a more complete balancing of total benefits and costs. For the reasons cited below OPE recommends against inclusion of these costs in the benefit-cost calculation.

      Since the proposed Commission policy statement as revised would include routine emissions during normal conditions as well as releases under accident conditions, the $1,000/man-rem would be applied to exposure reductions under each of these conditions.

      A number of the commenters were opposed to inclusion of the economic benefit of reducing the risk of economic loss. The following comment by Duke Power Company summarizes the views of this group:

> The benefit side of the benefit-cost analysis should represent a measure of the potential reduction in risk only in terms of public health and safety. The NRC is not charged with, and should not concern itself with, protecting the financial investment of a utility and its shareholders in a nuclear plant. Likewise, neither the economic benefits of electricity produced by nuclear power plants, nor the potential economic losses associated with their operation come within the purview of the NRC. As a practical matter, the calculation of economic consequences of reactor accidents is much more difficult and subject to larger uncertainties than the evaluation of radiological consequences, and would thereafter unduly complicate the cost-benefit analyses.

None of the commenters were able to pin down exactly the relative importance in financial terms of economic damage (loss off-site and on-site) vis-a-vis the total value of man-rem averted under accident conditions.

b. Containment availability.

While endorsing the concept of a containment performance measure, the staff concluded that it would not be prudent to specify a design objective for containment availability at this time. They propose to develop such a containment performance objective during the next several years. The ACRS recommended inclusion of a containment function availability guideline but pointed out that the approach to its implementation would be different for plants with CP's and OL's than for plants "yet to be designed."

A number of other comments expressed opposition to inclusion of a containment function guideline. Reasons cited included:

- Containment function is effectively covered by specifying core melt frequency and public risk guidelines.

- Containment guidelines would be extremely difficult to formulate primarily because it would be inextricably coupled with precursor core melt sequences, and their likelihood.

- Such a guideline would add another level of complication and decrease the utilities' essential decision-making flexibility.

- In view of the current state-of-the-art for evaluating compliance with guidelines (i.e., the large uncertainties) addition of more guidelines will not necessarily result in safer plants.

- A containment guideline might result in modifications, such as core catchers or containment over pressure relief systems, that tend not to be cost effective.
- Guidelines should address public risk and not specify intermediate but related factors such as conditional probability of containment failure give a core melt.

The few (including a nuclear insurance group and one utility) who favored inclusion of a containment function guideline noted the following:

- Such a guideline would focus attention on this important safety system and assist in upgrading its reliability.
- As an element of the "defense-in-depth" concept, containment function should have standards.
- Any guidelines should include a measure of containment effectiveness under worst case (i.e., core melt) conditions.

We propose that the Commission not add a design objective for availability of containment function at this time. To formulate a valid, and not just arbitrary design objective requires more information on severe core damage and core melt scenarios than is now available. Moreover, when added to the other design objectives, it would complicate the safety goal structure and put more restraints on design freedom than we believe warranted. Lastly, the individual prompt mortality risk design objectives acts to a significant degree as a containment performance objective.

c. Implementation Plan

Six questions were asked regarding implementation of the Safety Goals. The first question sought guidance for decisions under uncertainty. Some commenters recommended no guidance, many commenters recommended that NRC prescribe how to perform probabilistic risk assessment (PRA) calculations, and others recommended use of best estimate values with judgment applied where uncertainties overlap the numerical guidelines. The ACRS recommended that the staff include an assessment of uncertainties in all PRA results and provide broad guidance on how to judge and proceed.

The second question sought guidance on resolution of possible conflicts among quantitative aspects of some issue. Some commenters stated that no conflicts are expected or that further guidance is not needed. Others recommended that further guidance be provided to resolve conflicts or that the guidelines be balanced so that conflicts are avoided.

The third question requested an approach for accident initiators which are difficult to quantify. Most commenters recommended a dual-pronged approach. They felt that most accident initiators could be quantified for a probabilistic analysis; however, sabotage should be handled deterministically. Other commenters recommended a deterministic approach for initiators which are difficult to quantify. The ACRS suggested that those factors which cannot be treated adequately by PRA methods should be treated by other means.

The fourth question on the implementation plan concerned the use of mean, median, 90 percent confidence, etc. Many commenters advocated further specification of the numerical guidelines and a few opposed it at this time. Some advocated use of best-estimate calculations and others, including ACRS, recommended the use of mean values. A few commenters wanted to use median.

The fifth question asked if further specification of the use of quantitative guidelines and methodology should be provided. While some commenters stated that no further specification should be provided, most commenters, including ACRS, were in favor of further specifications and many of them recommended use of the PRA Procedures Guide (NUREG/CR-2300).

The sixth question involved application of the numerical guidelines to the protection of individuals. The commenters were about evenly divided between those who would apply the numerical guidelines to the individuals at average risk and those who would apply the guidelines to the individuals at greatest risk.

The ACRS stated that numerical guidelines on individual risk should address the risk to the individuals subject to the largest risk of exposure. However, for operational convenience it may be acceptable to express such a guideline in terms of the average risk to an assumed biologically average individual, living within one mile from the site boundary, if it can be assumed that there would not be significant variations in risk to such individuals over this region and that the risk would be less at distances greater than a mile.

We propose that the Commission follow the NRC staff's advice contained in the action plan for implementation of the Safety Goals. This plan and its supporting documentation will provide the guidance sought by these six questions on implementation of the Safety Goals.

d. Risk aversion.

The comments offered by the utilities and utility-related industries and professional groups were unanimous in recommending against inclusion of a specific risk aversion factor. Many others also recommend against it. A number of reasons were cited:

- A risk aversion factor may over emphasize very low probability high consequence accidents which contribute little to the overall risk to public.
- Too many site-specific variables are involved to reach any meaningful value for a risk aversion factor.
- Risk aversion is already addressed by the conservatism of the proposed numerical guidelines, e.g., the plant performance guideline.
- Inclusion of a risk aversion factor would depend on an attempt to quantify the public perception of nuclear risks which are generally known to be variable with time and place.
- Safety goals should be based on objective estimates of risk not subjective perceptions.
- As a matter of equity the potential isolated victims of accidents and the potential victims of large accidents should be equally protected.

Those who favored the inclusion of a risk aversion factor advanced reasons such as the following

- The ACRS (NUREG-0739) proposal seems to be reasonable.
- Risk aversion should be taken into account; otherwise the safety goals will deviate significantly from popular values.
- The question how risk aversion might be taken into account for the more severe accidents (and it should) will need to be considered by experts.

- A catastrophic accident is intolerable.
- Risk aversion would recognize the nonlinearity of accident consequences, i.e., one severe accident does do more damage than a number of small accidents with the same total consequence.

The ACRS commented that the proposed statement not only did not include any element of risk aversion, but it provided a reactor located in a region of relatively high population density to impose greater societal risks than a reactor at a remote site. ACRS suggested that because society is risk averse, "at least to the extent that it prefers not to introduce the potential for very large accidents for activities other than those essential to society," the NRC safety policy should explicitly include measures intended to reduce the likelihood of large accidents.

We propose that the Commission not include a risk aversion factor because formulation of such a factor would involve arbitrary and subjective presumptions of public perceptions of risk. Moreover, it would over-emphasize the importance of preventing the very rare, severe accident which contributes less to the overall public risk than contributed by the more frequent, less severe accidents.

Enclosure:
As stated

cc: Samuel Chilk
Leonard Bickwit
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SAFETY GOALS FOR THE OPERATION OF NUCLEAR POWER PLANTS

I. INTRODUCTION

A. Purpose and Scope

In its response to the recommendations of the President's Commission on the Accident at Three Mile Island, the Nuclear Regulatory Commission (NRC) stated that it was "prepared to move forward with an explicit policy statement on safety philosophy and the role of safety-cost tradeoffs in the NRC safety decisions". This policy statement is a step in that direction. Current regulatory practices are believed to ensure that the basic statutory requirement, adequate protection of the public, is met. Nevertheless, current practices could be improved to provide a better means for testing the adequacy of and need for current and proposed regulatory requirements. The Commission believes that such improvement could lead to more coherent and consistent regulation of nuclear power plants, a more predictable regulatory process, a public understanding of the regulatory criteria that the NRC applies, and public confidence in the safety of operating plants. This statement of NRC safety policy expresses the Commission's views on the acceptable level of risks to public health and safety and on the safety-cost tradeoffs in regulatory decisionmaking.

This policy statement focuses on the risks to the public from the operation of nuclear power plants. These are the risks from release of radioactive materials from the reactor to the environment from normal operations as well as from accidents. The Commission will refer to these risks as the risks of nuclear power plant operation. Except as noted in the following sentence, it is our intent that the risks from various initiating mechanisms be taken into account to the best of the capability of current evaluation techniques. The safety goal does not include risks from the nuclear fuel cycle, from sabotage, or from diversion of nuclear material. In the evaluation of nuclear power plant operation, several categories of releases are considered by the staff. These categories are routine emissions; normally expected transients, design basis accidents; and severe reactor accidents. The risks to the public resulting from operating nuclear power plants are addressed in current NRC practice as follows. Before a nuclear power plant is licensed to operate, NRC prepares an environmental impact assessment which includes an evaluation of the radiological impacts of routine operation of the plant and accidents on the population in the region around the plant site. The assessment is subjected to public comment and may be extensively probed in adjudicatory hearings. For all plants licensed to operate, NRC has found that there will be no measureable radiological impact on any member of the public from routine operation of the plant. Moreover, the staff's overall assessment of the environmental risk of normally expected transients and design basis accidents shows that these risks are roughly comparable to the risk for normal operational releases although accidents have a potential for early fatalities and economic costs that cannot arise from normal operations. (Reference: NRC staff calculations of radiological impact on humans contained in Final Environmental Statements for specific nuclear power plants, e.g., NUREG-0779, NUREG-0812, and NUREG-0854.) The objective of the Commission's policy statement is to establish goals which limit to an acceptable level the radiological risk which might be imposed on the public as a result of the operation of nuclear power plants. While this policy statement includes the risks of normal operation, normally expected transients, and design basis accidents the Commission believes that these risks are small and therefore does not believe that they need to be routinely analyzed on a case-by-case basis in order to demonstrate conformance with the Safety Goal.

B. Development of This Statement of Safety policy

In developing this policy statement, the Commission has solicited and benefited from the information and suggestions provided by workshop discussions. Two NRC sponsored workshops have been held, the first in Palo Alto, California, on April 1-3, 1981 and the second in Harpers Ferry, West Virginia, on July 23-24. The first workshop addressed general issues involved in developing safety goals. The second workshop focused on a discussion paper which presented proposed safety goals. Both workshops featured discussions among knowledgeable persons drawn from industry, public interest groups, universities, and elsewhere, and representing a broad range of perspectives and disciplines.

The Commission also received and considered a Discussion Paper on Safety Goals for Nuclear Power Plants submitted in November 1981, by its Office of Policy Evaluation.

In arriving at a final decision on a statement of its nuclear power plant safety policy and goals, the Commission has taken into consideration the comments and suggestions received from the public in response to the Proposed Policy Statement on "Safety Goals for Nuclear Power Plants."

II. QUALITATIVE SAFETY GOALS

The Commission has decided to adopt qualitative safety goals supported by design objectives and operating limits for use during a trial period. The Commission notes that the staff has established operating limits in the action plan for implementing the safety goals. These operating limits are to be used in conjunction with the individual risk and plant performance design objectives. The Commission's first qualitiative safety goal is that the risk from operation of a nuclear power plant not be a significant contributor to a person's risk of death or injury. The intent is to require a level of safety such that individuals living or working near nuclear power plants should be able to go about their daily lives without special concern by virtue of their proximity to such plants. Thus, the Commission's first safety goal is:

> Individual members of the public should be provided a level of protection from the consequences of nuclear power plant operation such that no individual bears a significant additional risk to life and health.

The Commission also decided that a limit be placed on the societal risks posed by nuclear power plant operation. The Commission believes that, even though protection of individual members of the public inherently provides substantial societal protection, the risks of nuclear power plant operation should be further reduced to the extent that is reasonable achievable through the application of available technology. (This principle is already applied to the normal operation of nuclear power plants.) The use of a benefit-cost test on safety improvements to reduce societal risks is implicit in this goal. Thus, the Commission's second safety goal is:

> Societal risks to life and health from the operation of nuclear power plants should be as low as reasonably achievable.

The Commission believes that, by meeting the design objectives established to implement these qualitiative goals, the risks from the operation of nuclear power plants are comparable to or less than the total risks of the operation of competing electricity generating plants.

III. DESIGN OBJECTIVES

A. General Considerations

As used here, a design objective is an aiming point for public risk reduction which nuclear plant designers and operators should meet where feasible. Since the design objectives are aiming points and not firm requirements, there may be instances where nuclear plants may not achieve all of the objectives.

A key element in formulating a safety policy which establishes design objectives is to understand both the strengths and limitations of the techniques by which one judges whether these objectives have been met.

A major step forward in the development and refinement of accident risk quantification was taken in the Reactor Safety Study completed in 1975. The objective of the Study was "to try to reach some meaningful conclusions about the risk of nuclear accidents." The Study did not directly address the question of what level of risk from nuclear accidents was acceptable.

Since the completion of the Reactor Safety Study, further progress in developing probabilistic risk assessment and in accumulating relevant data has led to recognition that it is feasible to begin to use quantitiative reactor safety design objectives for limited purposes. However, because of the sizable uncertainties still present in the methods and the gaps in the data base -- essential elements needed to guage whether the objectives have been achieved -- the design objectives should be viewed as aiming points or numerical benchmarks which are subject to revision as further improvements are made in probabilistic risk assessment. In particular, because of the present limitations in the state of the art of quantitatively estimating risks, the design objectives are not substitutes for existing regulations.

B. Design Objectives

We want to make clear at the beginning of this section that no death attributable to nuclear power plant operation will ever be "acceptable" in the sense that the Commission would regard it as a routine or permissible event. We are discussing acceptable risks, not acceptable deaths. In any fatal accident, a course of conduct posing an acceptable risk at one moment results in an unacceptable death moments later. This is true whether one speaks of driving, swimming, flying or generating electricity from coal. Each of these activities poses a calculable risk to society and to individuals. Some of those who accept the risk (or are part of a society that accepts risk) do not survive it. We intend that no such accident(s) will occur, but the possibility cannot be entirely eliminated. Furthermore, this risk is less than the risk that society will accept from each of the other activities mentioned above during the same 30-year period, including generating the same amount of electricity from coal.

1. Individual Mortality Risks

The Commission has decided to adopt the following two design objectives:

> The risk to an average individual in the vicinity of a nuclear power plant site of prompt fatalities that might result from reactor accidents should not exceed one-tenth of one percent (0.1%) of the sum of prompt fatality risks resulting from other accidents to which members of the U.S. population are generally exposed.
>
> The risk to an average individual in the vicinity of a nuclear power plant site of cancer fatalities that might result from the operation of nuclear power plants should not exceed one-tenth of one percent (0.1%) of the sum of cancer fatality risks resulting from all other causes.

The Commission adopts this 0.1% ratio of the risks of nuclear power-plant operation to the risks of mortality from non-nuclear-plant origin to reflect the first qualitative goal, which would provide that no individual bear a significant additional risk. In addition, the 0.1% figure is consistent with the provision of the second qualitative safety goal, which seeks to keep risks as low as reasonable achievable. Calculations suggest that the risk of operation of a nuclear power plant is consistent with the design objectives and would compare favorably with risks of viable competing technologies. The 0.1% ratio to other risks is low enough to support an expectation that people living or working near nuclear power plants would have no special concern due to the plant's proximity.

The average individual in the vicinity of the plant is defined as the average individual biologically (in terms of age and other risk factors) and locationally who reside within a mile from the plant site boundary. This means that the average individual is found by accumulating the individual risks and dividing by the number of individuals residing in the vicinity of the plant.

For those nuclear power plant sites where no individual lives within the vicinity of the site, a hypothetical average individual located one mile from the site boundary will be assumed for risk estimation purposes.

Individuals in the vicinity of the plant site boundary would be subject to the greatest risk of death attributable to radiological causes. Beyond this distance, atmospheric dispersion of the airborne radioactive materials sharply reduces the radiation exposure levels and the corresponding risk of prompt or delayed fatality.

2. Benefit-Cost Guideline

The Commission has adopted a benefit-cost guideline for use in decisions on safety improvements which would reduce societal risks in accordance with the "as low as reasonably achievable" (ALARA) principle. It has decided that a guideline of $1,000 per man-rem averted be adopted for trial use. The value is to be in 1983 dollars. This value should be modified to reflect general inflation in the future.

> The benefit of an incremental reduction of societal mortality risks should be compared with the associated costs on the basis of $1,000 per man-rem averted.

This guideline is intended to encourage the efficient allocation of resources in safety-related activities by providing that the expected reduction in public risk that would be achieved should be commensurate with the costs of the proposed safety improvements. The benefit of an incremental reduction of societal mortality risks should be compared with the associated costs, including all reasonably quantifiable costs (e.g., design and construction of plant modifications, incremental cost of replacement power during mandated or extended outages, changes in operating procedures and manpower requirements).

Justification of proposed plant design changes or corrective actions would be related to the reduction in risk to society measured as a decrease in expected population exposure (expressed in man-rem). To take into account the fact that a safety improvement would reduce the public risk during the entire remaining lifetime of a nuclear power plant, both the estimated cost of the improvement and the benefit (risk reduction) should be adjusted to reflect only the remaining years during which the plant is expected to operate (i.e., annualized).

The NRC staff has some experience in the use of benefit-cost analysis and criteria in evaluating improvements in the treatment of routine radioactive effluents from nuclear power plants. In 1975 the Commission discussed a benefit-cost value of $1,000/man-rem reduction in the evaluation of improvements proposed to reduce routine radiation exposures. However, the use of a benefit-cost guideline in evaluating means for reducing population risks from power reactor operations would be new.

In applying the benefit-cost guideline for man-rem averted the Commission proposes that the population considered subject to significant risk be taken as the population within 50 miles of the plant site. A substantial fraction of exposures of the population to radiation would be concentrated within this distance. The individual risk design objective would ensure that the potential increase in delayed cancer fatalities from reactor operations at a typical site would be no more than a small fraction of the year-to-year normal variation in the expected cancer deaths from non-nuclear causes. That is, if the design objective is met for individuals in the immediate vicinity of the plant site, the risk to persons much farther away would be much lower than the limit set by the design objective. Thus, compliance with the design objective applied to individuals close to the plant would mean that the aggregated societal risk for a 50-mile-radius area would be a number of times lower than it would be if compliance with just a design objective applied to the population as a whole were involved.

The benefit-cost guideline establishes a means for determining if additional safety features are warranted for nuclear power plant sites, particularly those which are near areas of high population density. By meeting the design objective for individual cancer risk and applying the benefit-cost guideline, the risks to society will be sufficiently low such that there is no need for an additional design objective for limiting the risks to society from cancers and genetic effects. Therefore, achieving the individual cancer risk design objective and the benefit-cost guideline would satisfy the second qualitative safety goal.

3. Plant Performance Design Objective

An important objective of efforts to reduce the public risk associated with nuclear power plant operation is to minimize the chance of serious reactor core damage since a major release of radioactivity may result from accidents involving core damage. Because of the substantial uncertainties inherent in probabilistic risk assessments of potential reactor accidents, especially in evaluation of accident consequences, the Commission has decided to adopt a limitation on the probability of a core melt as an objective for NRC staff use in the course of reviewing and evaluating probabilistic risk assessments of nuclear power plants. This design objective may need to be revised as new knowledge and understanding of core performance under degraded cooling conditions are acquired. Thus, the Commission has selected the following design objective:

> The likelihood of a nuclear reactor accident that results in a loss of protective features leading to severe core damage should normally be less than one in 10,000 per year of reactor operation.

The Commission also recognizes the importance of mitigating the consequences of severe core damage and continues to emphasize containment, remote siting, and emergency planning as integral parts of the defense-in-depth concept.

IV. IMPLEMENTATION

The Commission's intention is that the design objectives and benefit-cost guideline would be used by the NRC staff in conjunction with probabilistic risk assessments and would not substitute for NRC's reactor regulations in 10 CFR Chapter 1. Rather, individual licensing decisions would continue at present to be based principally on compliance with the Commission's regulations. Regulatory decisions to use probabilistic risk assessment should be made on the basis of an appraisal of its value in the specific application. Thus, implementation of the statement of safety policy should not, by itself, mandate the use of probabilistic risk assessment.

The design objectives and benefit-cost guideline may be used during a trial period as one consideration in deciding whether corrective measures or safety improvements should be made in plants previously approved for construction or operation. The Commission believes that a trial period of 2 years should be adequate to permit an evaluation of the benefits of its safety policy.

In all applications of the design objectives and benefit-cost guideline, the probabilistic risk assessments, if performed, should be documented, along with the associated assumptions and uncertainties, and considered as one factor among others in the regulatory decisionmaking process. The nature and extent of the consideration given to the design objectives and benefit-cost guideline in individual regulatory decisions would depend on the issue itself, the quality of the data base, and the reach and limits of analyses involved in the pertinent probabilistic calculations. The design objectives and benefit-cost guideline should aid professional judgment, not replace judgment with mathematical forumlae.

The Commission has received from the staff a specific action plan for implementation of the design objectives and benefit-cost guideline. The plan indicates how the NRC staff plans to use the design objectives and benefit-cost guideline in conjunction with probabilistic risk assessments. The implementation plan appears reasonable for trial use and is attached to the Commission's safety goals policy statement. The staff proposes to apply design objectives as follows: (a) new construction permit applicants should achieve design objectives and evaluate further safety improvements in accordance with the benefit-cost guideline; (b) operating reactors and those reactors under operating license review need not achieve the design objectives -- but rather evaluation of any proposed safety improvements would be performed using the benefit-cost guideline. In addition, the staff is proposing operating limits, above the design objectives, which the NRC staff expects to be met by all reactors. In backfit decisions, the NRC staff intends to look most closely at whether the plant meets the plant performance design objective which specifies the likelihood of a nuclear reactor accident that results in loss of core protective features leading to severe core damage. The staff will also use probabilistic risk assessment techniques and the design objectives to assist in setting priorities for those research and inspection activities which are amenable to probabilistic risk assessment. The design objectives should assist in reviews of the adequacy of and necessity for new rules, standards, and guides amenable to probabilistic risk assessment and proposals or petitions to change existing ones. Also the design objectives should assist in the reviews of adequacy of and necessity for orders, bulletins, and circulars amenable to probabilistic risk assessment. The Commission believes the approach which underlies the staff's action plan is reasonable and that the plan should be reevaluated by the Commission after a period of trial use by the NRC staff.

~~SAFETY GOALS FOR NUCLEAR POWER PLANTS:-~~
~~A PROPOSED POLICY STATEMENT~~

SAFETY GOALS FOR THE OPERATION OF NUCLEAR POWER PLANTS

I. INTRODUCTION

A. Purpose and Scope

In its response to the recommendations of the President's Commission on the Accident at Three Mile Island, the Nuclear Regulatory Commission (NRC) stated that it was "prepared to move forward with an explicit policy statement on safety philosophy and the role of safety-cost tradeoffs in the NRC safety decisions". This ~~draft~~ policy statement is a step in that direction. Current regulatory practices are believed to ensure that the basic statutory requirement, adequate protection of the public, is met. Nevertheless, current practices could be improved to provide a better means for testing the adequacy of and need for current and proposed regulatory requirements. The Commission believes that such improvement could lead to more coherent and consistent regulation of nuclear power plants, a more predictable regulatory process, a public understanding of the regulatory criteria that the NRC applies, and public confidence in the safety of operating plants. ~~Ultimately, an explicit~~ This statement of NRC safety policy ~~is~~ expresses ~~needed.--Such a statement would state~~ the Commission's views on the acceptable level of risks to public health and safety and on the safety-cost tradeoffs in regulatory decisionmaking.

This ~~proposed~~ policy statement focuses on the risks to the public from the operation of nuclear power plants. ~~one matter of special public concern at the present time: -- nuclear power plant accidents which may~~ These are the risks from release of radioactive materials from the reactor to the environment~~.~~ from normal operations as well as from accidents. The Commission will refer to these risks as the risks of nuclear power plant operation. Except as noted in the following sentence, it is our intent that ~~nuclear power plant accident~~ the risks from various initiating mechanisms be taken into account to the best of the capability of current evaluation techniques~~,~~. ~~even where uncertainties (as with earthquakes) may be substantial.~~ The safety goal does not include risks ~~from routine emissions,~~ from the nuclear fuel cycle, from sabotage, or from diversion of nuclear material. In the evaluation of nuclear power plant operation, several categories of releases are considered by the staff. These categories are routine emissions; normally expected transients; design basis accidents; and severe reactor accidents. The risks to the public resulting ~~from routine emissions~~ from operating nuclear power plants are addressed in current NRC practice as follows. Before a nuclear power plant is licensed to operate, NRC prepares an environmental impact assessment which includes an evaluation of the radiological impacts of routine operation of the plant and accidents on the population in the region around the plant site. The assessment is subjected to public comment and may be extensively probed in adjudicatory hearings. For all plants licensed to operate, NRC has found that there will be no measurable radiological impact on any member of the public from routine operation of the plant. Moreover, the staff's overall assessment of the environmental risk of normally expected transients and design basis accidents shows that these risks are roughly comparable to the risk for normal operational releases although accidents have a potential for early fatalities and economic costs that cannot arise from normal operations. (Reference: NRC staff calculations of radiological impact on humans contained in Final Environmental Statements for specific nuclear power plants, e.g., NUREG-0779, ~~and~~ NUREG-0812, and NUREG-0854.) The objective of the ~~present-proposed~~ Commission's policy statement is to ~~develop~~ establish goals ~~for~~ which limit~~ing~~ to an acceptable level the ~~additional-potential~~ radiological risk which might be imposed on the public as a result of ~~accidents at~~ the operation of nuclear power plants. While this policy statement includes the risks of normal operation, normally expected transients, and design basis accidents the Commission believes that these risks are small and therefore does not believe that they need to be routinely analyzed on a case-by-case basis in order to demonstrate conformance with the Safety Goal.

B. Development of This Statement of Safety Policy

In developing this ~~draft~~ policy statement, the Commission has solicited and benefited from the information and suggestions provided by workshop discussions. Two NRC-sponsored workshops have been held, the first in Palo Alto, California, on April 1-3, 1981 and the second in Harpers Ferry, West Virginia, on July 23-24. The first workshop addressed general issues involved in developing safety goals. The second workshop focused on a discussion paper which presented proposed safety goals. Both workshops featured discussions among knowledgeable persons drawn from industry, public interest groups, universities, and elsewhere, and representing a broad range of perspectives and disciplines.

~~Finally, the~~ The Commission also received and considered a Discussion Paper on Safety Goals for Nuclear Power Plants, submitted in November 1981, by its Office of Policy Evaluation.

In arriving at a final decision on a statement of its nuclear power plant safety policy and goals, the Commission ~~will take~~ has taken into consideration the comments and suggestions received from the public in response to ~~this draft statement.~~ the Proposed Policy Statement on "Safety Goals for Nuclear Power Plants."

II. QUALITATIVE SAFETY GOALS

The Commission ~~proposes~~ has decided to adopt qualitative safety goals supported by ~~provisional numerical guidelines.~~ design objectives and operating limits for use during a trial period. The Commission notes that the staff has established operating limits in the action plan for implementing the safety goals. These operating limits are to be used in conjunction with the individual risk and plant performance design objectives. The Commission's ~~proposes as its~~ first qualitative safety goal is that the risk from operation of a nuclear power plant ~~accident~~ not be a significant contributor to a person's risk of ~~accidental~~ death or injury. The intent is to require a level of safety such that individuals living or working near nuclear power plants should be able to go about their daily lives without special concern by virtue of their proximity to such plants. Thus, the Commission's first ~~proposed~~ safety goal is:

- Individual members of the public should be provided a level of protection from the consequences of nuclear power plant ~~accidents~~ operation such that no individual bears a significant additional risk to life and health.

The Commission also decided ~~proposes~~ that a limit be placed on the societal risks posed by nuclear power plant operation. The Commission believes that, ~~reactor accidents. This proposed goal has two elements. First,~~ even though protection of individual members of the public inherently provides substantial societal protection, the risks of nuclear power plant operation ~~accidents should be such that, when added to the risk of normal operation, the total risk to the public from an operating nuclear power plant would be comparable to or less than the risk from other viable means of generating the same quantity of electrical energy. Second, the risks of accidents~~ should be further reduced to the extent that is reasonably achievable through the application of available technology. (This principle is already applied to the normal operation of nuclear power plants.) The use of a benefit-cost test on safety improvements to reduce societal risks is implicit in this goal. Thus, the Commission's second ~~proposed~~ safety goal is:

- Societal risks to life and health from the operation of nuclear power plants ~~accidents~~ should be as low as reasonably achievable. ~~and should be comparable to or less than the risks of generating electricity by viable competing technologies.~~

~~The comparative part of this goal is to be interpreted as requiring that the risks from accidents should be low enough that the total risks~~ The Commission believes that, by meeting the design objectives established to implement these qualitative goals, the risks from the operation of nuclear power plants ~~resulting from normal operation and accidents~~ are comparable to or less than the total risks of the operation of competing electricity generating plants.

III. ~~PROVISIONAL-NUMERICAL-GUIDELINES~~ DESIGN OBJECTIVES

A. General Considerations

As used here, a design objective is an aiming point for public risk reduction which nuclear plant designers and operators should meet where feasible. Since the design objectives are aiming points and not firm requirements, there may be instances where nuclear plants may not achieve all of the objectives. A key element in formulating a safety policy which establishes design objectives ~~numerical-guidelines-~~ is to understand both the strengths and limitations of the techniques by which one judges whether these ~~guidelines~~ objectives have been met.

A major step forward in the development and refinement of accident risk quantification was taken in the Reactor Safety Study completed in 1974[5]. The objective of the Study was "to try to reach some meaningful conclusions about the risk of nuclear accidents." The Study did not directly address the question of what level of risk from nuclear accidents was acceptable.

Since the completion of the Reactor Safety Study, further progress in developing probabilistic risk assessment and in accumulating relevant data has led to recognition that it is feasible to begin to use quantitative reactor safety ~~guidelines~~ design objectives for limited purposes. However, because of the sizable uncertainties still present in the methods and the gaps in the data base -- essential elements needed to guage whether the objectives ~~guidelines~~ have been achieved -- the ~~quantitative-guidelines~~ design objectives should be viewed as aiming points or numerical benchmarks which are subject to revision as further improvements are made in probabilistic risk assessment. In particular, because of the present limitations in the state of the art of quantitatively estimating risks, the ~~numerical-guidelines~~ design objectives are not substitutes for existing regulations.

B. ~~Numerical-Guidelines~~ Design Objectives

We want to make clear at the beginning of this section that no death attributable to a nuclear power plant operation ~~accident~~ will ever be "acceptable" in the sense that the Commission would regard it as a routine or permissible event. We are discussing acceptable risks, not acceptable deaths. In any fatal accident, a course of conduct posing an acceptable risk at one moment results in an unacceptable death moments later. This is true whether one speaks of driving, swimming, flying or generating electricity from coal. Each of these activities poses a calculable risk to society and to individuals. Some of those who accept the risk (or are part of a society that accepts the risk) do not survive it. We intend that no such accident(s) will occur, but the possibility cannot be entirely eliminated. Furthermore, this risk is less than the risk that society will accept from each of the other activities mentioned above during the same 30-year period, including generating the same amount of electricity from coal.

1. Individual ~~and Societal~~ Mortality Risks

The Commission has decided to adopt ~~proposes~~ the following two ~~provisional numerical guidelines:~~ design objectives:

- The risk to an average individual ~~or to the population~~ in the vicinity of a nuclear power plant site of prompt fatalities that might result from reactor accidents should not exceed one-tenth of one percent (0.1%) of the sum of prompt fatality risks resulting from other accidents to which members of the U.S. population are generally exposed.

- The risk to an average individual ~~or to the population~~ in the vicinity of ~~area near~~ a nuclear power plant site of cancer fatalities that might result from ~~reactor accidents~~ the operation of nuclear power plants should not exceed one-tenth of one percent (0.1%) of the sum of cancer fatality risks resulting from all other causes.

The Commission adopts ~~proposes~~ this 0.1% ratio of the risks of nuclear power-plant ~~accidents~~ operation to the risks of ~~accidents of~~ mortality from non-nuclear-plant origin to reflect the first qualitative goal, which would provide that no individual bear a significant additional risk. In addition, the 0.1% figure is consistent with the provision of the second qualitative safety goal, which seeks to keep risks as low as reasonably achievable. ~~It is also consistent with the comparative provision of the second qualitative safety goal, since c~~Calculations suggest that the risk of ~~accidents at~~ operation of a nuclear power plant ~~that~~ is consistent with the proposed ~~numerical guidelines~~ design objectives and would compare favorably with risks of viable competing technologies. The 0.1% ratio to other ~~accident~~ risks is low enough to support an expectation that people living or working near nuclear power plants would have no special concern due to the plant's proximity.

The average individual in the vicinity of the plant ~~risk~~ is ~~taken~~ defined as the ~~estimated-probability-of-fatality from-a-nuclear-power-plant-accident-for-an-individual-in-the-vicinity-of-the-plant, -including-prompt-deaths-and delayed-deaths.--The-individual-risk-limit-is-applied-to the-biologically-average-individual~~ average individual biologically (in terms of age and other risk factors)~~.~~ and locationally who resides at a location within 1 mile from the plant site boundary. This means that the average individual is found by accumulating the individual risks and dividing by the number of individuals residing in the vicinity of the plant.

For those nuclear power plant sites where no individual lives within the vicinity of the site, a hypothetical average individual located one mile from the site boundary will be assumed for risk estimation purposes.

~~In applying the numerical guideline for prompt fatalities as a population guideline, the Commission proposes to define the vicinity as the area within 1 mile of the nuclear power plant site boundary since calculations of the consequences of major reactor accidents suggest that individuals in the population within a mile~~ Individuals in the vicinity of the plant site boundary would be subject to the greatest risk of ~~prompt~~ death attributable to radiological causes. Beyond this distance, atmospheric dispersion ~~and radioactive decay~~ of the airborne radioactive materials sharply reduces the radiation exposure levels and the corresponding risk of prompt or delayed fatality.

~~In applying the numerical guideline for cancer fatalities, as a population guideline, the Commission proposes that the population considered subject to significant risk be taken as the population within 50 miles of the plant site. A substantial fraction of exposures of the population to radiation would be concentrated within this distance. This guideline would ensure that the potential increase in delayed cancer fatalities from all reactor accidents at a typical site would be no more than a small fraction of the year-to-year normal variation in the expected cancer deaths from non-nuclear causes. Moreover, the limit protecting individuals provides even greater protection to the population as a whole. That is, if the guideline is met for individuals in the immediate vicinity of the plant site, the risk to persons much farther away would generally be much lower than the limit set by the guideline. Thus, compliance with the guideline applied to individuals close to the plant would generally mean that the aggregated societal risk for a 50-mile radius area would be a number of times lower than it would be if compliance with just the guideline applied to the population as a whole were involved.~~

2. Benefit-Cost Guideline

The Commission ~~proposes~~ has adopted a benefit-cost guideline for use in decisions on safety improvements which would reduce ~~individual-and-~~societal risks ~~below-the-levels specified-in-the-first-and-second-numerical-guidelines~~ in accordance with the "as low as reasonably achievable" (ALARA) principle. It has decided ~~proposes~~ that a of $1,000 per man-rem averted be adopted for trial ~~provisional~~ use. ~~and-subject-to-revision-in-the-light-of-public-comments.~~ The value is to be in 1983 dollars. This value should be modified to reflect general inflation in the future.

- The benefit of an incremental reduction of ~~risk -----below-the-numerical-guidelines-for~~ societal mortality risks should be compared with the associated costs on the basis of $1,000 per man-rem averted.

This guideline is intended to encourage the efficient allocation of resources in safety-related activities by providing that the expected reduction in public risk that would be achieved should be commensurate with the costs of the proposed safety improvements. The benefit of an incremental reduction of ~~risk below the numerical guidelines for~~ societal mortality risks should be compared with the associated costs, including all reasonably quantifiable costs (e.g., design and construction of plant modifications, incremental cost of replacement power during mandated or extended outages, changes in operating procedures and manpower requirements).

Justification of proposed plant design changes or corrective actions would be related to the reduction in risk to society measured as a decrease in expected population exposure (expressed in man-rem). ~~under accident conditions.~~ To take into account the fact that a safety improvement would reduce the public risk during the entire remaining lifetime of a nuclear power plant, both the estimated cost of the improvement and the benefit (risk reduction) should be adjusted to reflect only the remaining years during which the plant is expected to operate (i.e., annualized).

The NRC staff has some experience in the use of benefit-cost analysis and criteria in evaluating improvements in the treatment of routine radioactive effluents from nuclear power plants. In 1975 the Commission discussed a benefit-cost value of $1,000/man-rem reduction in the evaluation of improvements proposed to reduce routine radiation exposures. However, the use of a benefit-cost guideline in evaluating means for reducing population risks from power reactor operations ~~accidents~~ would be new.

In applying the benefit-cost guideline for man-rem averted the Commission proposes that the population considered subject to significant risk be taken as the population within 50 miles of the plant site. A substantial fraction of exposures of the population to radiation would be concentrated within this distance. The individual risk design objective would ensure that the potential increase in delayed cancer fatalities from reactor operations at a typical site would be no more than a small fraction of the year-to-year normal variation in the expected cancer deaths from non-nuclear causes. That is, if the design objective objective is met for individuals in the immediate vicinity of the plant site, the risk to persons much farther away would be much lower than the limit set by the design objective. Thus, compliance with the design objective applied to individuals close to the plant would mean that the aggregated societal risk for a 50-mile-radius area would be a number of times lower than it would be if compliance with just a design objective applied to the population as a whole were involved.

The benefit-cost guideline establishes a means for determining if additional safety features are warranted for nuclear power plant sites, particularly those which are near areas of high population density. By meeting the design objective for individual cancer risk and applying the benefit-cost guideline, the risks to society will be sufficiently low such that there is no need for an additional design objective for limiting the risks to society from cancers and genetic effects. Therefore, achieving the individual cancer risk design objective and the benefit-cost guideline would satisfy the second qualitative safety goal.

3. Plant Performance ~~Guideline~~Design Objective

An important objective of efforts to reduce the public risk associated with nuclear power plant operation is to minimize the chance of serious reactor core damage since a major release of radioactivity may result from accidents involving core damage. Because of the substantial uncertainties inherent in probabilistic risk assessments of potential reactor accidents, especially in evaluation of accident consequences, the Commission ~~proposes~~ has decided to adopt a limitation on the probability of a core melt as a ~~provisional-guideline~~ an objective for NRC staff use in the course of reviewing and evaluating probabilistic risk assessments of nuclear power plants. ~~It-is-likely-that-this-guideline~~ This design objective ~~will~~ may need to be revised as new knowledge and understanding of core performance under degraded cooling conditions are acquired. Thus, the Commission has selected ~~proposes-~~ the following design objective ~~guideline~~:

> ~~Large-Scale-Core-Melt:~~ The likelihood of a nuclear reactor accident that results in a ~~large-scale~~ loss of ~~core-melt~~ protective features leading to severe core damage should normally be less than one in 10,000 per year of reactor operation.

The Commission also recognizes the importance of mitigating the consequences of a severe core ~~core-melt-accident,~~ damage and continues to emphasize containment, remote siting, and emergency planning as integral parts of the defense-in-depth concept.

IV. IMPLEMENTATION

~~The-application-and-prospective-regulatory-use-of-safety-goals-and associated-numerical-guidelines-are-important-considerations-in-a-Commission-decision-whether-to-adopt-a-particular-proposed-set-of goals-and-guidelines.~~ The Commission's intention is that the ~~goals,~~ design objectives and benefit-cost guidelines would be used by the NRC staff in conjunction with probabilistic risk assessments and would not substitute for NRC's reactor regulations in 10 CFR Chapter 1. Rather, individual licensing decisions would continue at present to be based principally on compliance with the Commission's regulations. Regulatory decisions to use probabilistic risk assessment should be made on the basis of an appraisal of its value in the specific application. Thus, implementation of the statement of safety policy should not, by itself, mandate the use of probabilistic risk assessment.

The design objectives and ~~proposed numerical~~ benefit-cost guideline may be used during ~~the~~ a trial period as one consideration in deciding whether corrective measures or safety improvements should be made in plants previously approved for construction or operation. The Commission believes that a trial period of 2 years should be adequate to permit an evaluation of the benefits of its safety policy. ~~Benefits should be measured in terms of estimated annual reduction in radiological risk due to reactor accidents. Costs of safety improvements should be annualized over remaining plant life.~~

In all applications of the ~~goals and~~ design objectives and benefit-cost guidelines, the probabilistic risk assessments, if performed, should be documented, along with the associated assumptions and uncertainties, and considered as one factor among others in the regulatory decisionmaking process. The nature and extent of the consideration given to the design objectives and benefit-cost ~~numerical~~ guidelines in individual regulatory decisions would depend on the issue itself, the quality of the data base, and the reach and limits of analyses involved in the pertinent probabilistic calculations. The ~~proposed numerical~~ design objectives and benefit-cost guidelines should aid professional judgment, not replace judgment with mathematical formulase.

The Commission ~~is-requesting~~ has received from the staff ~~to-develop~~ a specific action plan for implementation of the design objectives and benefit-cost ~~proposed-qualitative-safety-goals-and-numerical guidelines,~~- The plan ~~should~~ indicates ~~for-Commission-review-and approval~~-how the NRC staff plans to use the ~~goals,-and~~ design objectives and benefit-cost guidelines in conjunction with probabilistic risk assessments. The implementation plan~~,~~ appears reasonable for trial use and ~~along-with-the-public-comments-on-this-policy-statement and-the-discussion-paper-(NUREG-0880),-will-be-considered-by-the--- Commission-in-reaching-a-final-decision-on-the-adoption-of-a-reactor safety-policy-statement-and-its-associated-goals-and-guidelines~~ is attached to the Commission's safety goals policy statement.

The staff proposes to apply design objectives as follows: (a) new construction permit applicants should achieve design objectives and evaluate further safety improvements in accordance with the benefit-cost guideline; (b) operating reactors and those reactors under operating license review need not achieve the design objectives -- but rather evaluation of any proposed safety improvements would be performed using the benefit-cost guideline. In addition, the staff is proposing operating limits, above the design objectives, which the NRC staff expects to be met by all reactors. In backfit decisions, the NRC staff intends to look most closely at whether the plant meets the plant performance design objective which specifies the likelihood of a nuclear reactor accident that results in loss of core protective features leading to severe core damage. The staff will also use probabilistic risk assessment techniques and the design objectives to assist in setting priorities for those research and inspection activities which are amenable to probabilistic risk assessment. The design objectives should assist in reviews of the adequacy of and necessity for new rules, standards, and guides amenable to probabilistic risk assessment and proposals or petitions to change existing ones. Also the design objectives should assist in the reviews of adequacy of and necessity for orders, bulletins, and circulars amenable to probabilistic risk assessment. The Commission believes the approach which underlies the staff's action plan is reasonable and that the plan should be reevaluated by the Commission after a period of trial use by the NRC staff.

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#13
#5

MEMORANDUM FOR: L. G. Hulman, Chief
Accident Evaluation Branch, DSI

FROM: Wm. H. Regan, Jr., Chief
Siting Analysis Branch, DE

SUBJECT: SEABROOK UNITS 1 AND 2 DEIS INPUT AND POPULATION PROJECTIONS FOR THE YEAR 2000

Attached, as requested by your branch, is the input for Section 5.9.2.1.3(2) S Site Features of the Seabrook DEIS, and the population projections for the year 2000 out to a distance of 500 miles around the Seabrook site. The applicant's projections were used for the year 2000 permanent resident population within a 50 mile radius of the plant. The corresponding transient population projections within a 10 mile radius were obtained from the applicant's 1980 transient population data by applying a growth factor and appropriate weighting factors. The weighting factors were used to obtain average transient population estimates from peak weekend and weekday transient population values. The growth factor was determined on the basis of the BEA projections to the year 2000.

The 50-500 mile data are based on the relative BEA areas within the radii of interest, in conjunction with the "SECPOP" computer run using latitude 42°53'55.4" N and longitude 70°50'58.7"W. Areas beyond the United States boundaries (i.e., Canadian Provinces) were included in the analysis and were adjoined to the computer results for the BEA areas. The Canadian population numbers were derived from the data in the Canadian Almanac and Directory, 1978, the Webster's New Geographical Dictionary, 1980, and the World Almanac, 1980.

This input was prepared by K.M. Campe of the Siting Analysis Branch.

~~8203100061~~ XA

Original signed by W. H. Regan, Jr.

Wm. H. Regan, Jr., Chief
Siting Analysis Branch
Division of Engineering

Attachment:
As stated

OFFICE▸	DE:SAB:SAS	DE:SAB:SAS	DE:ET:SAB
SURNAME▸	KMCampe:clb	LSoffer	WHRegan
DATE▸	2/16/82	2/ /82	2/ /82

5.9.2.1.3(2)

The NRC's reactor site criteria, 10 CFR Part 100, require that the site for every power reactor have certain characteristics that tend to reduce the risk and potential impact of accidents. The discussion that follows briefly describes the Seabrook site characteristics and how they meet these requirements.

The site has an exclusion area as required by 10 CFR Part 100. The minimum exclusion area distance from either reactor unit is 3000 feet (914 meters). With some exceptions, the exclusion area is located within the 896 acre site owned by the Public Service Company of New Hampshire. The exceptions consist of the Boston and Maine Railroad easement, the Exeter and Hampton Electric Company underground power transmission line easement, and portions of the Brown's River and Hunt's Island Creek. The applicants' authority to determine all activities within the exclusion area with respect to the above easements and waterways is still under review by the staff. The results of the evaluation will be reported in the staff's Safety Evaluation Report.

Beyond and surrounding the exclusion area is a low population zone (LPZ), also required by 10 CFR Part 100. The LPZ for the Seabrook site is a circular area with a 1.25 mile (2012 meter) radius centered at the midpoint of the centerline between Unit 1 and 2 reactors. This area encompasses the property owned by the applicants, as well as property not owned by them. The LPZ is traversed by U. S. Route 1 and several feeder roadways, as well as a spur of the Boston and Maine Railroad. There is one school within the LPZ, the Seabrook Elementary School, south of the site and near the LPZ boundary. The school enrollment (including school staff) was about 740 in 1978, and is currently projected to drop to about 705 by mid-1980's. The principal industrial facility within the LPZ is the Bailey Division of USM Corporation, a manufacturer of plastic, rubber, and metal goods, and employing 930 people. There are several commercial establishments (i.e., shops, restaurants, etc.), as well as two shopping centers, within the LPZ. All of the above site features are located near the LPZ boundary in the western and southern directions from the site. Although a portion of Hampton Harbor and sections of several tidal brooks and rivers which are used for recreational purposes are located within the LPZ, the major beaches in the area are located east of Route 1A in Salisbury, Massachusetts and Seabrook and Hampton, New Hampshire, and are outside the LPZ. The number of permanent residents within the LPZ at Unit 1 startup (in 1983) is estimated to be 2160 persons. This is projected to increase to about 4400 persons by the year 2025. Within the LPZ the applicant must provide assurance that there is a reasonable probability that appropriate protective measures could be taken on behalf of the residents and other members of the public in the event of a serious accident. For a discussion of the applicant's protective actions, including evacuation of people in the vicinity of the Seabrook site, see the following section on Emergency Preparedness.

10 CFR Part 100 also requires that the distance from the reactor to the nearest boundary of a densely populated area containing more than about 25,000 residents be at least one and one-third times the distance from the reactor to the outer boundary of the LPZ. Since accidents more hazardous than those commonly

postulated as representing an upper limit are conceivable, although highly improbable, it was considered desirable to add the population center distance requirement in Part 100 to provide for protection against excessive exposure doses to people in large centers. The applicant indicates that presently the nearest densely populated center of more than about 25,000 persons is Portsmouth, N.H. located about 12 miles NNE of the Seabrook site with a 1980 population of 26,214 persons. The applicant has also examined future growth for nearer communities and has concluded that either Amesbury, Massachusetts, located 4 miles SSW, or Newburyport, Massachusetts, located 6 miles SSW could become the nearest population center. The 1980 populations of Amesbury and Newburyport were 13,961 and 15,910 persons, respectively. The population center distance is at least one and one-third times the LPZ outer radius regardless of whether the nearest population center were designated to be Portsmouth, Amesbury or Newburyport. The transient population associated with seasonal activity at Hampton and Seabrook beaches about 2 miles east of the site is sufficiently large that the Atomic Safety and Licensing Appeal Board (ASLAB) in the course of the Construction Permit hearings, directed that the beach areas to the east of the site be considered the nearest densely populated center. The Board ruled that Route 1A to the east of the site serves as the real boundary of the populated area. Since the nearest approach of Route 1A is 1.67 miles from the Seabrook site, the population center distance is at least one and one-third times the LPZ, as required by 10 CFR Part 100. The largest city within 50 miles is Boston, Massachusetts, with a 1980 population of about 562,000 persons, located about

40 miles SSW of Seabrook. The projected population density within 30 miles of the site in 1983 is a maximum of about 530 persons per square mile at 2 miles from the plant. The projected population density within 30 miles in the year 2025 is also expected to reach a maximum at about 2 miles and is projected to be about 1150 persons per square mile.

The safety evaluation of the Seabrook site has also included a review of potential external hazards, i.e., activities offsite that might adversely affect the operation of the plant and cause an accident. This review encompassed nearby industrial, transportation, and military facilities that might create explosive, missile, toxic gas or similar hazards. The risk to the Seabrook facility from such hazards has been found to be negligibly small. A more detailed discussion of the compliance with the Commission's siting criteria and the consideration of external hazards are given in the staff's Safety Evaluation Report.

SEABROOK

TOTAL POPULATION ESTIMATE (RESIDENTS
PROJECTED TO THE YEAR 2000. TRANSIENT

SECTOR DEG. / MILES	-11.3 – 11.3 N	11.3 – 33.8 NNE	33.8 – 56.3 NE	56.3 – 78.8 ENE	78.8 – 101.3 E	101.3 – 123.8 ESE	123.8 – 146.3 SE	146.3 – 168.8 SSE
0-1	32	—	—	—	—	—	—	20
1-2	114	15	218	3,883	3,303	2,711	120	155
2-3	1,007	2,853	1,577	3,377	—	—	1,509	512
3-4	1,246	3,300	4,154	312	—	—	—	1,215
4-5	850	732	2278	—	—	—	—	1,751
5-10	7,806	12,424	3,089	—	—	—	—	3,390
10-20	27,400	34,800	2,800	—	—	—	8,900	14,800
20-30	32,700	11,500	—	—	—	—	900	29,300
30-40	22,300	18,300	—	—	—	—	—	—
40-50	6,900	43,300	—	—	—	—	—	—
50-60	5,479	102,818	1,882	—	—	—	—	2,197
60-70	5,420	88,387	89	—	—	—	—	7,016
70-85	19,017	52,968	9,385	—	—	—	462	11,530
85-100	14,994	112,460	815	—	—	—	—	72,577
100-150	57,242	64,502	—	—	—	—	—	4,838
150-200	12,503	4,407	—	—	—	—	—	—
200-350	753,696	138,654	431,919	931,396	10,193	—	—	—
350-500	252,549	294,659	691,502	648,877	—	—	—	—

SECTOR DEG. MILES	168.8 – 191.3	191.3 – 213.8	213.8 – 236.3	236.3 – 258.8	258.8 – 281.3	281.3 – 303.8	303.8 – 326.3	326.3 – 348.8
	S	SSW	SW	NSW	W	WNW	NW	NNW
0-1	213	413	102	—	172	210	30	30
1-2	523	468	1,177	1,355	1,743	92	294	380
2-3	782	537	441	1,067	418	329	207	204
3-4	649	554	253	378	538	93	164	292
4-5	1,409	456	3,944	3,778	1,349	1,099	515	489
5-10	8,958	10,661	13,097	9,431	4,645	4,865	9145	7,819
10-20	20,500	22,300	73,100	28,700	24,300	16,300	13,200	16,950
20-30	189,000	177,600	204,600	125,800	63,600	16,200	4,200	20,700
30-40	107,500	957,100	194,000	151,200	118,800	72,700	12,100	15,900
40-50	127,900	883,600	190,400	41,200	30,800	40,600	19,800	6,400
50-60	298,454	251,682	176,865	120,418	15,750	10,947	40,730	10,480
60-70	107,876	191,187	360,227	57,389	11,323	5,978	10,074	7,188
70-85	216,443	847,667	139,957	50,212	55,724	42,171	14,609	6369
85-100	231,508	363,910	99,715	226,307	30,324	40,316	41,675	3631
100-150	7,735	345,068	1,937,880	777,203	704,689	132,134	129,193	70,666
150-200	—	65,898	3,497,565	716,064	619,686	37,708	271,974	83,109
200-350	—	420	28,236,580	2,957,958	3,131,168	348,762	899,812	175,058
350-500	—	46,794	8,045,132	4,550,213	3,162,113	324,012	220,490	159,664

SEABROOK

WEIGHTED TRANSIENT POPULATION WITHIN 10 MILES PROJECTED TO THE YEAR 2000.

SECTOR DEG.	-11.3 – 11.3	11.3 – 33.8	33.8 – 56.3	56.3 – 78.8	78.8 – 101.3	101.3 – 123.8	123.8 – 146.3	146.3 – 168.8
MILES	N	NNE	NE	ENE	E	ESE	SE	SSE
0-1	12	—	—	—	—	—	—	—
1-2	14	15	108	3,153	2,523	1,181	30	5
2-3	247	73	287	2,027	—	—	779	152
3-4	96	50	1,934	132	—	—	—	1,215
4-5	90	12	878	—	—	—	—	1,721
5-10	386	164	1,089	—	—	—	—	3,390
10-20	—	—	—	—	—	—	—	—
20-30	—	—	—	—	—	—	—	—
30-40	—	—	—	—	—	—	—	—
40-50	—	—	—	—	—	—	—	—
50-60	—	—	—	—	—	—	—	—
60-70	—	—	—	—	—	—	—	—
70-85	—	—	—	—	—	—	—	—
85-100	—	—	—	—	—	—	—	—
100-150	—	—	—	—	—	—	—	—
150-200	—	—	—	—	—	—	—	—
200-350	—	—	—	—	—	—	—	—
350-500	—	—	—	—	—	—	—	—

SECTOR / DEG.	168.8 - 191.3	191.3 - 213.8	213.8 - 236.3	236.3 - 258.8	258.8 - 281.3	281.3 - 303.8	303.8 - 326.3	326.3 - 348.8
MILES	S	SSW	SW	WSW	W	WNW	NW	NNW
0-1	3	3	2	—	2	—	—	—
1-2	113	8	67	245	623	2	14	40
2-3	32	27	11	47	8	9	17	14
3-4	29	14	3	8	8	3	14	12
4-5	309	16	324	68	19	19	365	9
5-10	558	741	177	401	135	135	595	219
10-20	—	—	—	—	—	—	—	—
20-30	—	—	—	—	—	—	—	—
30-40	—	—	—	—	—	—	—	—
40-50	—	—	—	—	—	—	—	—
50-60	—	—	—	—	—	—	—	—
60-70	—	—	—	—	—	—	—	—
70-85	—	—	—	—	—	—	—	—
85-100	—	—	—	—	—	—	—	—
100-150	—	—	—	—	—	—	—	—
150-200	—	—	—	—	—	—	—	—
200-350	—	—	—	—	—	—	—	—
350-500	—	—	—	—	—	—	—	—